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SUDBURY ENVIRONMENTAL STUDY

TWO INTENSIVE FIELD STUDIES OF DISPERSION OF THE INCO 381 METRE STACK PLUME IN THE CONVECTIVE BOUNDARY LAYER

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Ontario
Ministry of the Environment

The Honourable
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Minister

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Deputy Minister

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SUMMARY

In June 1978 and July 1979, the Air Resources Branch carried out intensive field programs in the Sudbury area to study the dispersion of the Inco 381 metre stack plume in the convective boundary layer. The studies were designed to provide experimental data for the verification of a short term, short range fumigation model (4) for the estimation of ground level concentrations of SO_2 due to this stack's emissions.

The studies provided a set of data suitable for checking the validity of the model predictions. They also provided a set of intense meteorological measurements from which characteristics of the convective boundary layer in the Sudbury area were determined.

It was found that the convective boundary layer exhibits a typical pattern under relatively warm sunny conditions. It grows rapidly from roughly 0900 until roughly 1300 hours local time after which it remains relatively constant until shortly before sunset.

The height of the convective layer is generally demarked by a strong capping inversion. Within the layer (in a barotropic CBL) the wind speed and potential temperature is approximately constant with height. The relatively long-lived convective turbulence elements within the layer bring about rapid vertical mixing which often causes portions of the plume to reach ground level very close to the stack.

CONCLUSIONS

Field studies were carried out in June 1978 and August 1979 into dispersion of the INCO 381 m stack plume in the convective boundary layer (CBL). The studies provided data for the validation of a computer model for estimating ground level SO_2 concentrations resulting from the INCO 381 M stack emissions under convective conditions (4). The data are reported in a format directly applicable to this purpose.

The model development and validation are published elsewhere (3,4). A good comparison was obtained between the model predictions and the field study data.

In addition to providing data for model validation, the field studies also provided an opportunity to study the characteristics of the convective boundary layer in the Sudbury area. A number of conclusions resulted from this work. They are:

- The CBL develops from roughly 0900 to 1300 hours local time after which it remains quasi-steady-state for most of the afternoon . In the evening, the dissolution of the CBL is very rapid and occurs just before sunset.

- The mixed layer is generally characterized by a capping inversion, a constant wind speed and a constant potential temperature lapse rate (equivalent to the dry adiabatic lapse rate).

- Plume dispersion within the CBL is characterized by behaviour known as looping. On warm sunny days the INCO Supserstack plume begins looping typically between 1000 and 1100 hours and stops roughly one to two hours before sunset. The initial impingment of individual plume loops usually occurs at a distance of 3 to 10 km from the stack and results in intermittent, high, ground level concentrations. Farther downwind, the plume becomes well-mixed in the vertical. Concentrations are not as high, and less intermittent.

1. INTRODUCTION

In June 1978 and August 1979, the Air Resources Branch of the Ministry to the Environment carried out two intensive field studies in the Sudbury area. These studies were designed to investigate dispersion of the INCO 381 m stack plume in the convective boundary layer. Both studies were carried out under the auspices of the Sudbury Environmental Study.

The objectives of these intensive field studies are related to the very nature of dispersion of elevated pollutant releases in the convective boundary layer. A brief description of the latter is therefore given here based on other publications (1-3). The reader is referred to these publications for more detailed descriptions.

The boundary layer over land can be thought of as a three layer structure. Each of the layers is characterized by a separate set of parameters related to the turbulence in it. Beginning at the surface, the layers are:

1. The Surface Layer:

In the surface layer, wind shear is dominant in the production of turbulence. The layer is confined to a height range $Z < |L|$ where Z is height above ground and L is defined as the Obukhov length ($=-u^3_*/k(g/T)H_o$; with u_* being the friction velocity, T the average temperature in the layer, H_o the kinematic surface heat flux and k the von Karman constant). Within the layer the controlling parameters are Z, τ_o, H_o and g/T where τ_o is the surface shear stress. These parameters can be combined into a scaling velocity and temperature respectively , i.e.,

$$u_* = (\tau_o/\rho)^{1/2} \qquad (1)$$

$$T_* = -Ho/u_* \qquad (2)$$

Dimensionless groups formed with $U*$ and $T*$ become universal functions of Z/L within the layer.

2. The Free Convection Layer:

In this layer, shear stress is no longer dominant but height, Z, is still the significant length scale. It is suggested (1) that the upper limit of this sublayer is 0.1 Z_i where Z_i is the height of the mixed layer (discussed next). In the free convection layer the governing parameters are Z_i, H_o, and g/T and the scaling velocity and scaling temperature are:

$$u_f = (H_o Z(g/T))^{1/3} \quad (3)$$

$$T_f = H_o/u_f \quad (4)$$

3. The Mixed Layer:

The mixed layer is characterized by turbulence insensitive to height Z and shear stress τ_o. The height of the mixed layer is defined as the height of the lowest inversion base Z_i capping the layer and this height in the controlling length scale. The scaling velocity and scaling temperature are:

$$w* = (H_o Zi\,(g/T))^{1/3} \quad (5)$$

$$\theta* = H_o/w* \quad (6)$$

Within the mixed layer, dimensionless groups formed with $w*$ and $\theta*$ should be functions of Z/Z_i only.

The term "mixed layer" is generally used synonymously with the term "convective boundary layer (CBL)" which is defined as the portion of the atmosphere most directly affected by solar heating of the earth's surface. The heating results in the buoyant production of turbulence in the form of long-lived

updrafts and downdrafts. Rapid vertical mixing takes place because of these motions and this mixing extends to the top of the layer - generally one to two kilometers.

Under conditions of very strong mixing, the CBL is generally barotropic, i.e., surfaces of constant pressure are also surfaces of constant density. In these cases, wind speed does not change with height and the vertical profiles of both wind speed and potential temperature are constant with height to the top of the layer.

Smoke plumes emitted from elevated sources within the CBL exhibit behaviour described rather graphically as 'looping'. Looping results from portions of the plumes being caught in alternating, large-scale, turbulent updrafts and downdrafts immediately after release from the stack. Those portions of plumes emitted into downdrafts are often carried to ground level very close to the stack causing high ground level concentrations. Those portions of plumes emitted into updrafts are carried high into the mixed layer resulting in zero ground level concentrations near the stack. Further downwind these portions do reach ground level causing non-zero ground level concentrations.

Downwind of the stack, the strong vertical motions tend to mix the pollutants rather rapidly throughout the entire mixed layer and pollutant concentrations are relatively homogeneous in the vertical.

This report describes two intensive field studies carried out in the Sudbury area to investigate the high ground level concentrations caused by the INCO 381 m stack plume under convective conditions. This behaviour has been observed to occur from mid-April to late October on sunny days.

The Air Resources Branch under the auspices of the Sudbury Environmental Study decided to investigate this phenomenon and to develop a computer model to calculate impingement points and ground level concentrations when the plume is emitted into the CBL. Ultimately the model will be used to assess the impact of local emissions on air quality and dry deposition in the Sudbury area.

The computer model was developed by the Air Quality and Meteorology Section of the Air Resources Branch. To aid in the development and verification of this model, the Technology Development and Appraisal Section (now the Atmospheric Research and Speical Programs Section) planned and carried out both field studies. The experimental portions of the study were designed to simultaneously measure: (1) all input variables to the model (2) the location and magnitude of ground level concentrations of sulfur dioxide emitted from the INCO 381 m stack and (3) characteristics of the CBL in Sudbury.

This report describes the instrumentation, field programs and results of both studies. The reader is referred to other publications (3,4) for a detailed description of the model and its comparison with the field study data.

2. EXPERIMENTAL PROGRAM

The experimental programs for both field studies were designed to provide data for the verification of the computer model developed by the Air Quality and Meteorology Section and to study the characteristics of the convective boundary layer in the Sudbury area. In order to do this, three types of measurements were undertaken simultaneously, namely:

1. Ground level concentration measurements of SO_2 taken for comparison with predictions of the model.

2. Meteorological measurements of total incoming solar radiation, S (W/m^2); mixed layer wind speed, U (m/s); ambient temperature at stack height, T_a (^oC); and mixed layer height, Z_i (m). Data from these and surface heat flux measurements were also used to characterize the structure of the CBL.

3. In-stack measurements of SO_2 emission rate, Q_s (g/s); stack gas temperature, T_s (^oC); and stack gas velocity, V_s (m/s). These measurements were carried out by INCO as part of their Emission Reduction Program and data were provided to the Ministry of the Environment after each study. These measurements are to be used as input to the model.

The instrumentation and methods used for these measurements are discussed in detail below. A brief summary is also given in Tables 1(a) and 1(b).

2.1 GROUND LEVEL CONCENTRATION MEASUREMENTS

The instrumentation for the ground level concentration measurements was similar for both field studies. It consisted of two measurement platforms- each outfitted with a fast-response SO_2 continuous analyser - the Sign -X, a Hewlett-Packard Strip Chart Recorder and a Topaz 1 Kw inverter. In the June study, one platform was mounted in a van and the other in a twin-engine Piper Aztec aircraft. In the August study, both platforms were mounted in station wagons and no aircraft was used. In all cases, the inlet to the Sign - X was mounted outside the region of aerodynamic distortion about the transport unit.

The vehicles used in the August 1979 study carried additional support instrumentation for assisting in the concentration measurements. Both carried ground-recovery intervalometers which maintained the speed of the chart recorders at a speed dependent on that of the vehicle. One of the vehicles (instrumented by and rented from Moniteq Ltd. of Toronto), also carried a MARSS 100 UV Absorption Spectrometer. This instrument was a prototype manufactured by Moniteq Ltd. and was taken to Sudbury for field testing. It was used to locate the overhead burden of SO_2 which helped define the boundaries of the plume.

A Barringer Research Ltd Correlation Spectrometer (COSPEC) was also provided by Moniteq and was used in the other vehicle for the same purpose. Use of the latter type of spectrometer for plume tracking has been well documented (5,6) and both instruments proved very useful in this study.

The experimental program was designed to provide simultaneous ground level SO_2 concentration measurements at two different distances downwind of the stack. One Sign - X was therefore deployed in the near field (5 to 15 Km from the stack) and the other in the far field (15 to 40 Km). The aircraft was always used in the far-field because air transport regulations prevented low level flying over areas near the stack. It should be pointed out that it was not always possible to obtain simultaneous near-field and far-field measurements because of logistical problems. However, the data from one instrument only was also satisfactory for the model verification.

The field measurement procedures were relatively simple. Each day, at the onset of convective activity, the plume direction was noted. A topographical map was used to locate roadways running roughly perpendicular to the axis of the plume. The vehicles were deployed to these roads where they

carried out repeated cross-wind traverses roughly perpendicular to the plume axis. Naturally, the traverses followed existing roadways so that the directions of individual portions of the traverses were variable. Bench marks were located along each traverse path and marked on the chart record of the Sign - X ouput. This allowed easy ground path recovery for later data analysis.

Five to twenty cross-wind traverses were made at each location within the duration of an hour. The importance of this number and time of traverses is discused in another publication (7). However, because of plume meandering, steady wind shifts, lack of roadways and/or operator problems, it was not always possible to obtan the desired number and frequency of traverses.

In the August 1979 field study, the remote sensors (i.e COSPEC and MARSS 100) delineated the edges of the plume quite clearly. This was very helpful in determining the location to begin a new traverse.

Also in the August 1979 study, the Mobile Air Monitoring Unit (MAMU) of the Monitoring and Instrumentation Development Unit carried out simultaneous stationary sampling along the traverse path of the near-field mobile vehicle. The purpose of this sampling was to assess the representativeness of the time-averaged cross-wind concentration profiles to stationary time-averaged concentrations. The MAMU was generally placed close to the center-line of the impingement zone of the plume and remained stationary for at least half an hour while the mobile unit traversed back and forth past it. Unfortunately, most measurement days were characterized by strong wind shifts and it was difficult to get long-term average data suitable for the desired analysis.

Sampling in the MAMU was done for SO_2, NO, NO_2, NO_x, H_2S and O_3 as well as surface level wind speed, wind direction, temperature, relative humidity and net solar radiation. Specifics of the instrumentation are available elsewhere (8). It should be noted that during the MAMU sampling program, the

plume often was subject to continuous wind shifts. Because of this, there was difficulty in obtaining enough long term average concentration data to do the desired comparison.

Multipoint calibrations of the Sign - X instruments were carried out at least once every 2 days. The MAMU instrumentation was calibrated daily.

During both field studies, a brief intercomparison test was carried out on the two Sign - X instruments. Both instruments, in their respective vehicles, were parked a few metres apart in a plume impingement area. The measured concentrations from the two units were compared and the results showed excellent agreement.

2.2 METEOROLOGICAL MEASUREMENTS

Meteorological measurements were carried out concurrently with the ground-level SO_2 concentration mesurements. Double theodolite pilot balloon-minisonde ascents were carried out for the measurements of wind direction, wind speed and temperature in the vertical. The ascents began early in the morning and continued until early evening. The interval between releases was roughly one hour in the June study and 45 minutes in the August study. The continuous releases throughout the day were designed to provide information on the formation, growth and decay of the mixed layer as a function of time of day.

The instrumentation consisted of two Warren-Knight theodolites, an Aero Aqua AA3001 minisonde ground receiver and Aero Aqua balloons and minisonde transmitters.

The balloon release site was roughly 2 Km from the base of the INCO 381 m stack. The two theodolites were separated along baselines approximately 300 m long and aligned roughly perpendicular to the mean wind direction. The field procedures and data analysis methods were exactly the same as those used in the Sudbury Environmental Study Meteorological Field Program and are described in detail elswhere (9).

Continuous measurements of total incoming solar radiation were also measured throughout both field studies. A Kipp and Zonen solarimeter of wavelength range 300 nm to 2.5 um was used. It was permamently set up roughly 2.5 km from the stack. The solarimeter output was used as a surrogate for surface heat flux in the model.

2.3 STACK PARAMETER MEASUREMENTS

INCO Ltd. operates continuous temperature, velocity and SO_2 concentration monitors in the 381 m stack. The data are used in their Emission Reduction Program for the control of emissions under poor dispersion conditions (as required by a Ministry of the Environment Control Order). Hourly-averaged SO_2 emission rates were calculated by INCO as part of this system. Hourly-averaged values of buoyancy flux were calculated from the stack velocity and temperature measurments.

All stack-related data presented in this report have been provided by INCO. Details of their measurement systems are available in other reports (10).

2.4 HEAT FLUX MEASUREMENTS

In the convective boundary layer, one of the scaling parameters controlling diffusion is the convective velocity scale, w_*, defined in Equation 5 as

$$w_* = (gH_o Z_i/T)^{1/3} \quad (m/s)$$

Here, g is the gravitational acceleration term, H_o is the surface kinematic heat flux, Z_i is the average mixed layer height and T, the average mixed layer temperature. While the latter two variables are easily measured, the surface heat flux is not. Therefore, for this work the total incoming solar radiation, S, was used as a surrogate for heat flux according to:

$$H_o = AS \qquad (W/m^2) \qquad (7)$$

where H_o is the maximum daily heat flux and A is a linear proportionality constant typically varying from 0.1 to 0.55 depending on the surface.

In developing the computer model, a value of A=0.3 was assumed. An experimental investigation of A was also carried out by making simultaneous measurements of heat flux and solar radiation during both field studies. A number of different methods were employed for these measurements- only one of which was successful. All are described here briefly.

In June 1978, Dr. H. C. Martin of The Atmospheric Environment Service agreed to carry out micrometeorological measurements of heat flux and energy budget during the course of the field study. A micorometeorologial tower was erected in the valley north of Sudbury and measurements were taken on a half-hourly basis using eddy - correlation techniques. The experimental method, instrumentation and results of this work are described in detail elsewhere (12).

Also in the June 1978 field study, attempts were made to indirectly measure surface heat flux using airborne measurments of temperature. The basis for this measurement is outlined in detail in Appendix 1. It can be summarized briefly by stating that the surface heat flux is related to the

standard deviation of temperature fluctuations, σ_t measured in the convective boundary layer. Attempts were therefore made to measure σ_t from the same Piper Aztec aircaraft used in the concentration measurements program. The instrumentation for these measurements consisted of a Thermal Systems Incorporated fast-response hot-film anemometer system in the temperature measurement mode, a Hewlett-Packard Chart Recorder and a Hewlett-Packard 3964A FM Recorder. The probe of the anemometer was mounted 20 cm beyond the nose of the aircraft. The control module and recorders were mounted inside the aircraft cabin. The TSI output was recorded both on strip chart and FM recorder - the former for visual observation and the latter for computer analysis.

The measurements consisted of making two 30-50 Km cross-wind flights at a height of 100 m above ground level. These flights were made prior to the concentration profile measurments.

Unfortunately this measurement program was unsuccessful. The temperature signal was continuously contaminated by RF interference and further use of the data was impossible. Spectral analysis of the recorded temperature signals indicated that many sources of interference were present and could not be eliminated. The method was abandoned mid-way through the study and no further reference will be made to the measurements.

In the August 1979 study, another measurement method was used to infer the surface heat flux indirectly. Both the method and instrumentation were provided by Dr. B. Kerman of the Atmospheric Environment Service. Detailed descriptions of the theory, methodology and instrumentation are published elsewhere (13,14) but a short discussion is given here.

The instrumentation used was a laser scintillometer. It consisted of a 5 W He-Ne laser source and a remote photodetector. The post-detector signal processor produced a direct voltage output proportional to the variance of the logarithm of the received light intensity. This variance is related to the heat flux in a convective boundary layer and the algebraic relationship is known (see references).

Early each morning the laser scintillometer was placed in a vacant field roughly 2.5 km from the 381 m stack. Approximately 50 m separated the laser from the detector. Proper alignment was obtained by using a theodolite mounting system. The data, in the form of output voltages, were recorded on an Esterline-Angus portable chart recorder.

In analysing the data, a problem in the signal processing electronics was discovered. The effect of this problem on the measured data could not be quantified so further analysis was abandoned.

3. DATA ANALYSIS AND RESULTS

The meteorological and concentration data were analysed to produce results directly compatible with the computer model. This required that the meteorological data be analysed for mixed layer height, mixed layer wind speed, mixed layer temperature and incoming solar flux; the in-stack data for SO_2 emission rate and buoyancy flux; and the concentration data for time-averaged centre-line concentrations. The individual methods of analysis and their results are discussed below. An analysis of the characteristics of the convective boundary layer in Sudbury is also presented. Note that all times referred to are Local Standard (Daylight Savings) Time.

3.1 CONCENTRATION DATA

The cross-wind SO_2 ground-level concentration profiles were analysed specifically to produce Eulerian average centre-line peak concentrations for direct comparison with model predictions. For the June 1978 study the data analysis was carried out by Moniteq Ltd. of Toronto. For the August 1979, study the analysis was done by a MOE summer student under the supervision of Ministry of the Environment staff as an undergraduate thesis for the University of Toronto.

The method of analysis is a slightly modified version of a standard technique used in many other studies (5,6). It consisted of the following steps:

(a) Each of the cross-wind SO_2 profiles was screened to determine its usefulnes in the detailed analysis. Only blocks of data with a large number of consecutive traverses lasting greater than 20 minutes were accepted, although longer intervals were desired. Data were rejected if the profiles could not be completed (because the plume had passed beyond the end of the roadway) or if there was an insufficient number of traverses to provide a good average.

(b) The chart records of the individual profiles were checked against topographical maps on which the traverse path had been marked. The ground reference points were identified and the known distances between reference points were checked against the chart record.

(c) Individual SO_2 profiles were grouped into subsets which were appropriate for time-averaging. These subsets required that the plume direction be relatively steady and the plume be continuously looping. Subset averaging

intervals ranged from a minimum of 19 minutes to a maximum of 135 minutes for both studies. The minimum and maximum number of profiles averaged were 3 and 24 respectively. The largest and longest set of traverses provided the most desirable and accurate data.

(d) Each subset of profiles was analysed to produce Eulerian averages of gound level concentrations. An Eulerian average is defined as an average made with respect to a fixed reference frame (as opposed to a Lagrangian average which is made with respect to a moving reference frame). The analysis involved first digitizing the chart record profiles to produce concentration versus distance data along each traverse path. All of the individual profiles within a subset were then superimposed with respect to the ground reference points and the concentrations at each point along the traverse path were averaged. Figure 1(a) illustrates the individual profiles for one set of traverses and Figure 1(b) shows the resulting Eulerian average. Further details of the analysis method and the associated computer programs are given in References (15) and (16). Each subset Eulerian average was plotted and the magnitude and crosswind location of the peak concentration was obtained from the plot. This peak concentration was assumed to represent the centre-line concentration of the time-averaged plume and was directly comparable to the predicted concentrations from the model.

(e) The distance and direction of the centre-line concentration from the INCO stack was determined from topographic maps with the traverse locations marked on them.

(f) The Eulerian-average centre-line concentrations C(measured) and their respective distances from the stack were tabulated. These data appear in Columns 11 and 8 respectively in Tables 2 (a) and 2(b). .

3.2 METEOROLOGICAL DATA

The pilot-balloon-minisonde data were analysed to produce values of mixed layer height, mixed layer wind speed, and mixed layer temperature as a function of time of day.

To do this, the data were first analyzed to produce vertical profiles of wind speed, wind direction and temperature. The method of analysis and its associated computer program is described in another publication (9). Figure 2 shows a sample plot of one profile. The complete set for both field studies is presented in Appendix 2.

From these profiles, a determination of the mixed layer height and mixed layer wind speed and direction was made. The method of determination was similar to that of Kaimal et al (1) and consisted of scanning the profile for the elevation at which a strong capping temperature inversion existed and/or the wind speed increased significantly after being relatively constant and/or the wind direction became constant after varying slightly. It was not necessary to use all of these criteria to determine the mixing height for every balloon release but, in most cases, more that one criterion was used. In some cases it was not possible to determine the mixed layer depth from the profiles because the measurements did not extend high enough.

After the mixing height was determined, the representative mixed layer wind was calculated by resolving the North-South and East-West vector componets of the wind speed. These were calcualted by vertically integrating the component wind speeds to the top of the mixed layer. The resultant wind speed and direction therefore represented a vector-average, vertically-integrated, mixed layer wind.

Finally, the solarimeter data were digitized to produce hourly averages of solar flux. These are tabulated in Tables 3(a) and 3(b) .

The daily variation of solar flux and mixing height is shown in Figures 3 to 24. Days for which no concentration data were available are included in the figures if a reasonable amount of meteorological data was available.

Once the solarimeter and mixed layer data were ready, further analyses were carried out to calculate the input data for the model. To do this, the solar flux, mixing height, and mixed layer wind speed were averaged over each interval for which Eulerian average concentration data were available.

3.3 HEAT FLUX DATA

The surface heat flux data obtained by Dr. H.C. Martin in June 1978 are presented in Reference (12). These data (obtained typically over 30 minute intervals) are also plotted in Figures 3 to 12 to show the diurnal variation of heat flux. Net radiation, R_N, data are also shown in these figures.

3.4 SOURCE DATA

The hourly-averaged in-stack temperature, velocity and SO_2 emission rate data were analysed for input to the model. This required estimating the actual time of emission of the portions of the plume sampled at ground level. This was done as follows: the average mixed layer wind speed and the distance from the stack for each set of traverses were determined. The time interval for each sampled portion of the plume to travel from the stack to its traverse location was calculated. This interval was then marked on a graph of emission rate, temperature and velocity versus time. An average value of each of these

parameters was determined from the graph for the estimated period of emission.

For input to the model, the value of Q was taken directly from the stack data while the values of stack temperature and velocity were used to calculate the average buoyuancy flux from the stack, i.e.

$$F = g V_s R_s^2 \frac{(T_s - Ta)}{T_s} \qquad (8)$$

where F = buoyancy flux (m^4/K^3)

g = acceleration due to gravity (m/s^3)

V_s = stack gas velocity (m/s)

R_s = radius of stack (m)

T_s = stack gas temperature (K)

Ta = ambient temperature at stack height (K)

It should be noted that the INCO Emission Reduction Program often caused the emission rate of SO_2 to change quite significantly in a short period of time. As a result, the estimated emission rate averages presented here are subject to a great deal of variation and could seriously affect model validation.

3.5 MODEL VALIDATION DATA

The final data used to validate the fumigation model are presented in Tables 2(a) and 2(b). The date, start time, end time, averaging time and number of passes are shown for each averaging interval in Columns 1 to 5. Columns 6 and 7 summarize the source data, i.e. the buoyancy flux, F and the SO_2 emission rate, Q. Column 8 gives the distance from the stack to the centre-line of the average profile. Column 9 lists the mixing height, Z_i and Column 10 the

convective velocity scale, w_*. Column 11 gives the mixed layer wind speed, u and the final column presents the measured, Eulerian average, centre-line SO_2 concentrations.

The accuracy of the data in Tables 2(a) and 2(b) is, in some cases, difficult to assess. The instantaneous individual stack parameters F and Q are accepted to be accurate within $\pm$ 10% (verbal communication, INCO Ltd.). The distance from the stack should be accurate to within $\pm$ 200 m and the height of the mixed layer should be within $\pm$ 15% of the actual value (based on earlier comparisons of aircraft SO_2 concentration and meteorological measurements). The estimates of convective scaling velocity have smaller uncertainties than any of the previous variables because of the one-third power dependence on the surface heat flux, the mixed layer height and the mixed layer temperature. Since it was not possible to measure surface heat flux and the adequacy of using solar flux as a surrogate is unknown, it was not possible to estimate the error in w_*. The mixed layer wind speed had an estimated accuracy of $\pm$ 20%. Finally, the Eulerian average concentration measurements are expected to be accurate to $\pm$ 25%.

It should be pointed out that the model performance is directly dependent on the quality of the SO_2 emission rate data used in it. While the accuracy of a particular hourly average emission rate is $\pm$ 10%, the uncertainties in the values shown in Tables 2(a) and 2(b) are much greater. This reflects the nature of the data and the requirements for analysing it. For example, on several occassions, the changes in SO_2 emission rate with time were extremely rapid as the smelter responded to the requirements of INCO'S Emission Reduction Program. These changes were reflected in the hourly average SO_2 emission rates measured from the in-stack monitors. However, the field measurements of ground level concentrations were always carried out over periods which did not correspond exactly to INCO'S hour-to-hour averaging period. It was

therefore necessary to estimate the emission rate for the measurement period by averaging the hourly - averaged data over the appropriate emission interval. Because of this, the impact of the rapidly changing emission rate on the measured ground level concentrations could be very significant. It is estimated that the uncertainty could be as high as ± 40% in some cases. This can seriously affect model validation and should be carefully considered. It is apparent that a steady - state emission source is more desirable for studies of this nature.

4. DISCUSSION

4.1 MODEL VALIDATION

A comparison of the prediction of the short range, short term fumigation model with the field observations is presented elsewhere (4). The comparison was good and is discussed quantitatively in the reference.

It should be noted that the centre-line concentration data used in the model validation have variable averaging times. As mentioned earlier, attempts were made to use the longest averaging time possible (within the limitations of the data) and the greatest number of traverses possible. To test the effects of the averaging time on the accuracy of the data and the model comparison, some of the August 1979 concentration data were analysed using different averaging intervals. That is, a given set of traverses was subdivided into several subsets which were averaged over their different time intervals. As expected, the comparison of model predictions with these concentration data showed a marked improvement with longer averaging times. A discussion of this is presented in detail in Reference (4).

4.2 CHARACTERISTICS OF THE CONVECTIVE BOUNDARY LAYER

The June and August intensive field studies provided an extensive data

base for determining the characteristics of the convective boundary layer in the Sudbury area. In general, these characteristics are very similar to those observed by Kaimal et al. (1) in Minnesota.

In both the June and August field studies, the height of the convective boundary layer was generally well-defined as the height of a strong daytime capping inversion. Under this inversion the wind speed was relatively constant with height but accelerated quickly above it. The potential temperature within the CBL was also relatively constant. The wind direction typically varied with height within the mixed layer but became roughly constant above it.

The diurnal cycle of the mixed layer followed a relatively consistent pattern. In the morning, the mixed layer developed rapidly as it responded to the increase in solar flux and the consequent increase in heat flux. This rapid growth generally occurred from 0900 to 1300 hours. At 1300 to 1400 hours, the mixed layer reached its maximum height and remained relatively constant until approximately 1800 hours.

Figure 25 illustrates this behaviour by showing the mixed layer height as a function of time for both field studies. The wide scatter in the data is a result of the changing metorological conditions which occurred during many of the days, such as rain events and overcast skies. However, the general pattern shows the rapid morning growth and the afternoon levelling off of the mixed layer. The maximum mixing height for both studies was 2300 m and the mid-day mixing height was typically around 1500 m.

Figure 26 illustrates the diurnal variation of the total incoming solar flux. While a great deal of scatter exists within the data (again, due to varying meteorological conditions), a sinusoidal variation is apparent. The maximum daily solar flux was reached at 1300 to 1400 hours. After the maximum was

reached, the afternoon decline in solar flux had no apparent effect on the relatively constant mixed layer height. This was because the solar flux continued to generate sufficient convective energy to maintain the strong mixing in the CBL. Although there were no field data collected to investigate this in Sudbury, Kaimal et al. (1) suggest that the evening change in the mixing height is rather abrupt when compared to the morning growth. Their Minnesota data indicate that the flux and, therefore, the mixing height decreased very rapidly about an hour before sunset. The drop in heat flux propogated downward from the top of the CBL so that the surface heat flux was the last to turn negative.

The late afternoon-early evening behaviour of the plumes from the INCO 381 m stack and another 93 m stack (of Falconbridge Nickel Mines Ltd.) provided some evidence that the dissolution of the CBL in Sudbury also follows this pattern. For instance Kaimal et al. indicate that the heat flux turns negative from the top of the mixed layer down roughly to ground level at an hour before sunset. At this time in Sudbury, one can see the INCO 381 m stack plume begin looping with progessively smaller-scale loops while the Falconbridge plume continues to loop vigorously. This suggests that the vertical mixing is decreasing in intensity and the mixed layer height is continuously dropping in response to the decreasing heat flux. Within a very short time, the mixed layer height appears to have descended to just above the INCO 381 m stack. The plume then undergoes very small scale looping and most of it rises above the capping inversion over which it is trapped. However, the bottom portions of some loops are still caught in CBL and are brought to ground level by the remaining vertical downdrafts. Ground level impingements from these loops still occur but are less frequent, lower in concentration, and shorter in duration than afternoon ground level concentrations. While this is occurring, the Falconbridge plume continues looping.

Finally, near sunset, the CBL has descended to well below the effective height of the Superstack plume and no looping takes place. The plume at this time often takes on the appearance of a set of large discrete puffs with clear air in between. By sunset, both the INCO and Falconbridge plumes have stopped looping and convective activity has ended.

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Table 1 (a)
June 1978 Field Study Experimental Program

TYPE	MEASUREMENT	INSTRUMENTATION	METHOD	VARIABLE
1. Meteorological	1. Solar radiation 300 nm to 2.5 um	Kip and Zonen Solarimeter	Continuous stationary record	1. Incoming solar flux (from which Q_*, w_* and Z_i can be inferred)
	2. Pilot balloon-minisonde releases	Double Warren-Knight Theodolites with Aero Aqua minisondes and AA305 MHz Receiver	Hourly releases 2 Km from stack	1. Vertical wind speed distribution, mixed layer wind speed U, 2. Vertical wind direction distribution, mixed layer wind direction, O. 3. Vertical temperature distribution, potential temp. lapse rate in and above the mixed layer, mixed layer height, Z_i.
2. GL SO_2 Concentration	1. Vehicle (van)	Sign-X Continuous SO_2 Analyser, Hewlett-Packard 982 Strip Chart Recorder, Topaz Inverter	Multiple cross-wind roadway traverses approximately perpendicular to plume axis	1. Eulerian and Lagrangian average cross-wind GLC profiles at 3-15 km from stack. 2. Maximum Eulerian GLC as a function of downwind and cross-wind distance from the stack.
	2. Aircraft (Piper Aztec)	Sign-X Continuous SO_2 Analyser, HP Strip Chart Recorder, Topaz Inverter	Mutiple Cross-wind traverses at tree-top level approximately perpendicular to the plume axis.	1. Eulerian and Lagrangian average cross-wind pseudo-GLC profiles from 15-30 km from stack 2. Maximum time-averaged GLC at 15-30 km from stack 3. Estimated height of mixed layer Z_i

Table 1(e) Cont'd

June 1978 Field Study Experimental Program

TYPE	MEANS.	INSTR.	METHOD	VARIABLE
3. Turbulence	1. Ground Level (Dr. H.C. Martin AES)	Instrumented Micro-meteorological tower for heat flux and energy budget measurements (see Reference)	Eddy-Correlation measurements	1. Ground level Heat flux, Q_o
	2. Aircraft	TSI Hot Film Temperature Sensor. HP FM Recorder.	Cross-wind low-level traverses	1. Standard deviation of temperature to infer heat flux Q.

Table 1 (b)

August, 1979 Field Study Experimental Program

TYPE	MEASUREMENT	INSTRUMENTATION	METHOD	VARIABLE
1. Met	Solar Radiation 300 nm to 2.5 nm	Kip and Zonen Solarimeter	Continuous record	Incoming solar flux for inferring Q_o, w_* and Z_i
	Pilot balloon - minisonde releases	Double Warren-Knight Theodolites with Aero Aqua Minisonde and Minisonde Receiver	Three-quarter-hourly releases 2 km from stack	1. Vertical wind speed distribution, mixed layer wind speed. 2. Vertical wind direction distribution, mixed layer wind direction 3. Vertical temperature distribution, potential temperature lapse rate in and above mixed layer mixed layer height Z_i
2. GL SO_2 Concentration	Vehicles	Sign-X Continuous SO_2 Monitors Hewlett-Packard Strip Chart Recorders, Topaz Inverters, Ground path recovery intervalometers.	Multiple cross-wind traverses approximately perpendicular to plume axis. At different distances downwind.	1. Eulerian and Lagrangian average cross-wind GLC profiles. 2. Maximum GLC - Eulerian and Lagrangian average
	Mobile Air Monitoring Unit	SO_2, NO, NO_x, O_3, H_2S plus ground level met conditions	Stationary sampling within impingement zone	1. Stationary time-average GLCs for variables measured
3. SO_2 Overhead Burden	Vehicles	Barringer Correlation (COSPEC) Monitaq Ltd MARKS 100 Spectrometer	Concurrent measurements with SO_2 GLC's	1. Existence of overhead plume
4. Heat Flux	Ground Level	Lasermeter custom built by AES (ref.)	Continuous output of light intensity fluctuations at a location where heat flux could easily be measured.	1. Directly measures C_T^2 from which surface heat flux, Q_o can be inferred.

Table 2 (a)

Summary of field data collected during the June 1978 field study
(* - airborne data)

DA	MO	YR	START TIME	END TIME	AVERAGING TIME (min)	NO. OF PASSES	F ($m^4 s^{-3}$)	Q_{-1} (gs^{-1})	X (m)	Z_i (m)	W_e (ms^{-1})	U_{-1} (ms^{-1})	C (Meas) ($ug\ m^{-3}$)
10	06	78	13:45	14:32*	47	8	2082	28213	3100	1040	2.13	11.3	208
			14:02	15:00*	58	7	2149	32224	39000	940	2.16	11.7	260
			15:56	17:12*	76	10	2072	22958	32000	740	2.31	10.2	494
11	06	78	16:10	17:11	61	12	1897	22958	3000	1540	2.80	13.8	182
13	06	78	13:34	15:00*	86	20	2590	33330	9200	1640	2.58	10.5	520
			13:01	13:35*	34	5	2703	33884	15500	1640	2.48	8.9	390
			16:30	17:04*	34	7	2481	27383	5100	1840	2.66	10.3	780
			16:44	17:20*	36	6	2481	27383	18000	1840	2.66	11.5	832
			17:23	17:54*	31	6	2489	30426	13800	1940	2.64	10.3	312
14	06	78	10:28	12:43	135	24	2761	32086	6000	1140	1.93	9.0	572
			13:03	13:26*	23	5	2768	35681	12000	1740	2.28	7.6	832
			13:31	14:05*	34	5	2753	35681	21000	1740	2.35	6.0	390
			16:00	16:30*	30	6	2477	25171	18000	1440	2.54	5.8	156
			16:03	16:49*	46	6	2425	23649	38000	1340	2.54	5.7	910
			16:34	17:10*	36	6	2534	37894	23500	1440	2.55	5.6	260
20	06	78	12:02	12:43*	41	6	2375	24479	18000	790	2.22	6.8	520
			12:27	13:24*	57	9	2445	18671	6500	940	2.32	7.0	520
			12:53	13:38*	45	6	2416	21575	29000	840	2.40	7.0	338
			16:18	17:26*	68	8	2454	26830	23500	1590	2.38	8.3	312
23	06	78	12:56	13:23*	27	5	1965	14660	15500	1240	2.37	5.0	338
			13:05	14:32*	87	14	1854	11064	4100	1240	2.44	5.5	286
			17:02	17:55*	53	10	2327	22820	10500	1340	2.55	9.0	624
27	06	78	15:37	16:38	61	10	2495	28075	4700	1690	2.51	9.0	234
			16:21	16:57*	36	6	2495	28075	20000	1640	2.55	8.1	390
			17:08	17:39*	29	5	2474	28628	32000	1740	2.58	8.1	416

TABLE 2 (b)

Summary of field data collected during the August 1979 field study

DA	MO	YR	START TIME	END TIME	AVERAGING TIME (min)	NO. OF PASSES	F ($m^4 s^{-3}$)	Q (gs^{-1})	X (m)	Z_i (m)	U_* (ms^{-1})	U (ms^{-1})	C (Meas) ($ug\ m^{-3}$)
16	08	79	1336	1448	72	9	1920	12800	5000	1100	2.05	3.4	390
			1458	1525	27	4	1918	15300	5500	1530	2.24	4.1	728
			1542	1645	63	8	1967	20830	5500	1300	1.93	4.5	572
22	08	79	1425	1457	32	4	2004	17800	16700	1000	2.03	3.2	494
			1510	1532	22	3	1991	15600	14400	1150	2.01	3.4	702
			1425	1532	67	7	1991	16100	14500	1100	2.01	3.7	520
			1539	1624	45	10	1990	12200	14000	1200	1.99	3.6	364
			1631	1735	64	6	2037	13100	13100	1200	1.83	3.7	338
			1541	1600	19	3	1978	13300	15600	1200	2.02	3.6	676
			1612	1700	48	5	2019	11900	15100	1200	1.89	3.7	754
			1541	1711	90	9	1990	12200	15100	1200	1.87	3.7	442
			1541	1700	79	8	1990	12100	15100	1200	1.87	3.7	390
			1725	1752	27	4	2013	15600	14700	1200	1.66	3.8	416
			1800	1826	26	5	2024	18500	14500	1200	1.47	3.8	702
			1725	1826	61	9	2011	16700	14600	1200	1.52	3.8	390
25	08	79	1303	1330	27	6	2250	23100	9100	1150	1.62	8.4	442

Table X(a)
Summary of Solar Radiation Data for June 1978

Solar Flux
WATTS/SQ. M.

HOUR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1-4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*	0	0	0	0	0	0	0	0	0	0	0
4-5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*	0	0	0	0	0	0	0	0	0	0	0
5-6	0	0	15	8	0	0	0	8	8	4	0	4	8	0	7	0	0	3	*	*	0	0	0	0	0	0	0	0	0	0
6-7	0	62	85	82	82	33	66	33	110	53	53	41	64	*	92	25	29	12	*	*	0	20	7	13	0	1	0	12	4	0
7-8	*	194	246	208	174	200	161	131	172	193	119	21	246	*	285	41	86	23	*	*	66	323	102	198	185	34	148	267	258	288
8-9	*	231	448	364	467	432	225	258	120	299	250	45	467	*	403	57	191	131	*	*	108	431	217	348	229	94	226	431	453	451
9-10	*	312	557	471	661	594	549	318	125	611	383	139	636	627	633	116	349	41	*	*	161	623	564	472	316	83	201	598	317	599
10-11	*	295	262	648	762	730	631	617	153	726	637	132	791	787	746	103	472	123	*	*	97	776	782	672	288	188	139	677	733	754
11-12	631	287	439	636	846	833	516	535	271	849	816	45	918	891	766	111	647	344	*	836	87	589	889	817	296	127	147	663	776	876
12-13	483	307	795	500	918	903	640	664	600	898	877	45	996	922	963	198	283	900	*	917	46	528	966	920	647	62	529	670	*	935
13-14	180	558	591	600	800	936	702	*	820	841	865	78	1010	885	977	459	513	977	*	930	66	399	1010	935	803	83	688	667	*	943
14-15	233	446	508	126	746	894	636	*	817	698	873	140	979	956	654	669	206	713	*	894	308	517	892	910	673	176	558	399	832	902
15-16	420	361	735	108	815	810	572	*	787	759	795	239	889	897	764	689	712	645	*	805	615	230	876	810	804	217	808	567	815	791
16-17	648	444	569	107	664	647	180	694	656	296	685	283	689	604	649	541	578	648	*	694	579	123	720	682	475	224	608	511	681	620
17-18	418	259	213	771	464	516	116	418	569	137	531	230	469	522	608	115	411	435	*	551	379	56	541	538	462	317	472	522	443	390
18-19	94	231	233	61	353	349	82	305	435	78	316	98	317	435	382	33	247	221	*	369	397	38	346	371	299	316	337	340	277	305
19-20	95	164	167	25	153	179	33	172	246	45	94	66	159	225	200	8	132	156	*	185	198	38	236	208	122	185	234	203	192	172
20-21	*	328	65	8	57	49	0	74	82	12	29	21	77	72	59	0	45	41	*	61	53	23	74	62	34	50	40	53	66	25
21-22	0	8	8	0	0	8	0	0	0	4	0	0	5	4	7	0	4	8	*	3	1	3	7	5	0	0	4	3	3	0
22-23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23-24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

*unavailable data

Table 3(b)

Summary of Solar Radiation Data for August 1979

Solar Flux
Watts/Sq. M.

Month August 1979

HOUR	Day 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1-4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6-7	49	0	41	8	0	41	0	0	57	0	40	33	0	0	123	0	0	0	0	*	0	67	0	0	0	0	0	0	0	*	*
7-8	180	0	147	106	106	172	0	164	166	49	172	164	0	0	186	102	70	0	0	*	0	327	33	0	41	0	0	25	15	*	*
8-9	352	16	328	335	237	360	49	352	123	311	344	164	156	543	279	213	0	0	475	57	410	93	41	78	0	268	207	27	*	*	*
9-10	524	47	492	516	311	590	57	524	549	393	541	500	180	174	756	393	397	0	164	496	147	573	129	145	398	442	393	330	51	*	*
10-11	664	32	631	696	532	614	66	680	655	369	655	754	90	238	821	502	467	23	143	666	156	898	190	105	553	593	317	287	82	*	*
11-12	803	279	532	680	623	819	66	736	827	254	672	836	90	215	793	688	604	72	245	721	467	775	110	106	694	683	229	164	178	*	*
12-13	795	213	657	664	672	819	106	827	819	623	786	983	74	162	819	696	682	92	592	797	819	838	109	371	797	706	436	162	78	*	*
13-14	770	123	385	688	860	819	139	868	819	106	754	934	115	188	903	707	725	162	715	674	809	846	118	680	453	741	498	578	41	*	*
14-15	655	197	492	508	827	713	98	827	811	115	705	721	131	203	850	786	850	188	698	59	754	706	104	266	272	595	236	678	203	*	*
15-16	713	688	467	352	655	721	8	737	623	172	688	729	115	160	686	700	532	174	614	113	635	512	63	716	205	580	66	492	113	*	*
16-17	557	573	603	336	590	623	270	655	401	172	631	673	*	86	633	578	106	133	635	307	475	496	45	604	*	416	80	160	123	*	*
17-18	475	524	410	213	451	549	467	557	229	147	516	524	*	20	510	471	160	121	508	139	313	340	57	401	*	317	66	172	82	*	*
18-19	188	377	336	98	328	323	327	385	147	197	426	336	*	0	258	225	76	106	598	96	133	185	29	143	*	205	20	119	82	*	*
19-20	82	197	147	57	164	197	180	205	74	188	213	139	*	0	170	115	82	86	663	20	20	60	16	20	*	0	0	43	20	*	*
20-21	41	74	57	0	57	57	57	57	0	57	66	41	*	0	37	37	27	41	288	0	0	0	0	0	*	0	0	0	0	*	*
21-22	0	0	0	0	0	0	0	0	0	0	0	0	*	0	0	0	0	150	0	0	0	0	0	0	0	0	0	0	-	*	*
23-24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23-24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

* - unavailable data

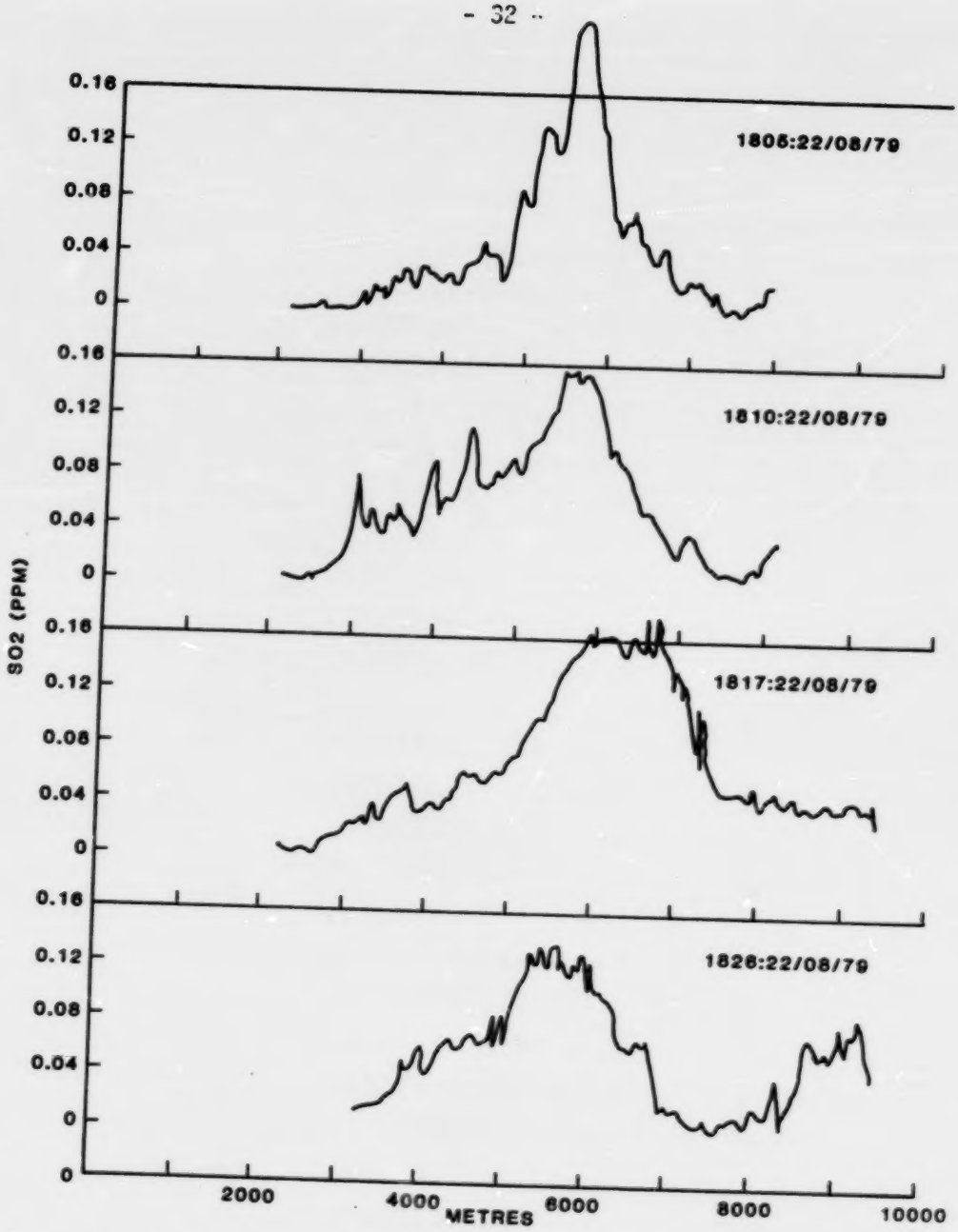


FIGURE 1(a): INDIVIDUAL CROSS-WIND CONCENTRATION PROFILES

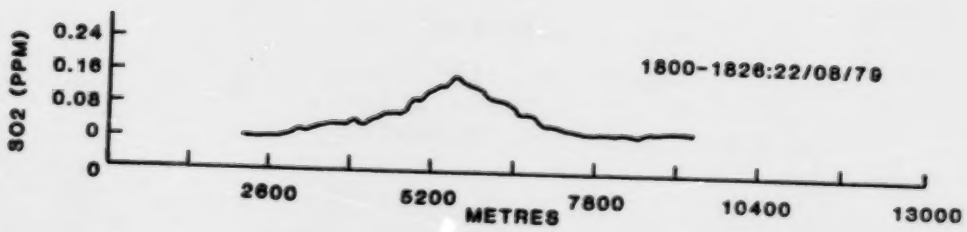


FIGURE 1(b): EULERIAN AVERAGE CONCENTRATION PROFILE

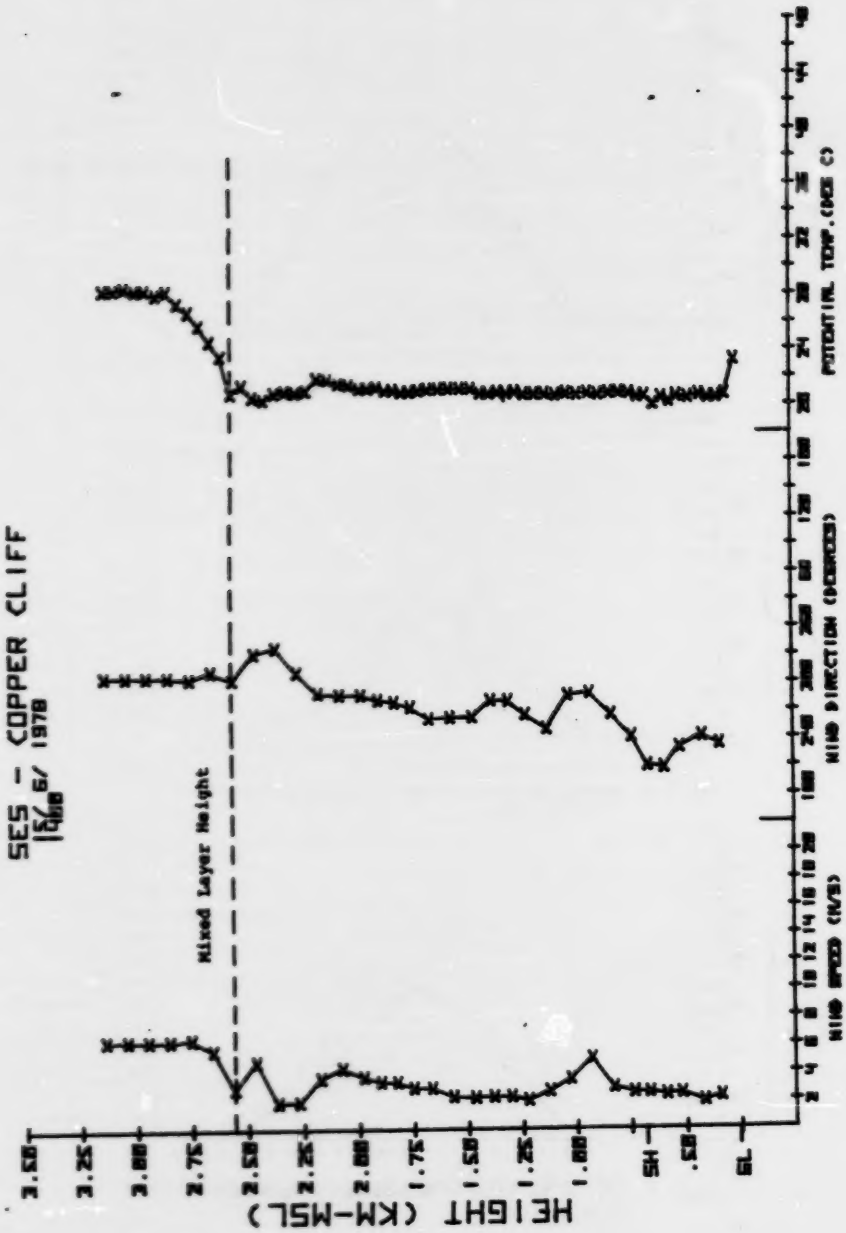


Figure 2: Vertical Profile of Wind Speed, Direction and Potential Temperature

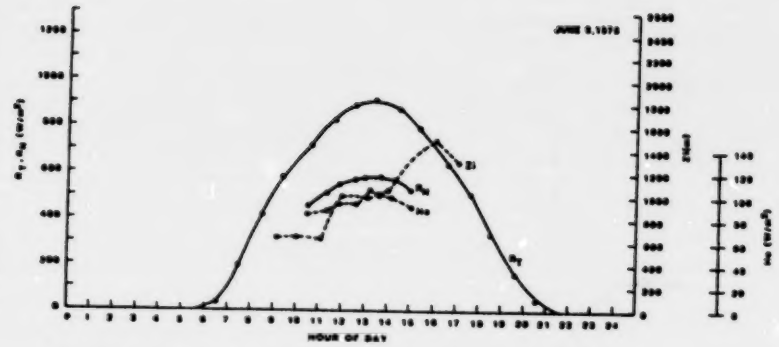


Figure 3: Diurnal Variation of Meteorological Parameters (June 6, 1978)

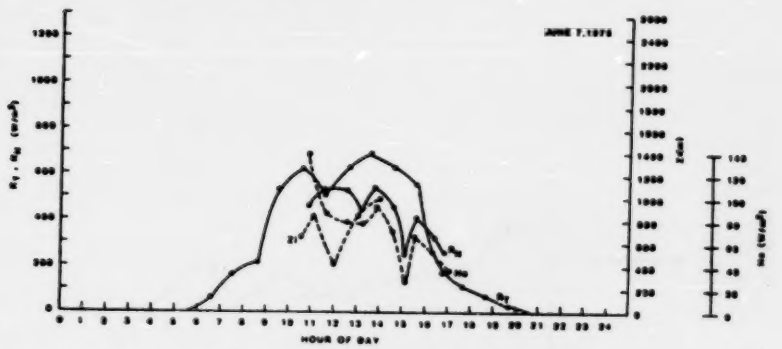


Figure 4: Diurnal Variation of Meteorological Parameters (June 7, 1978)

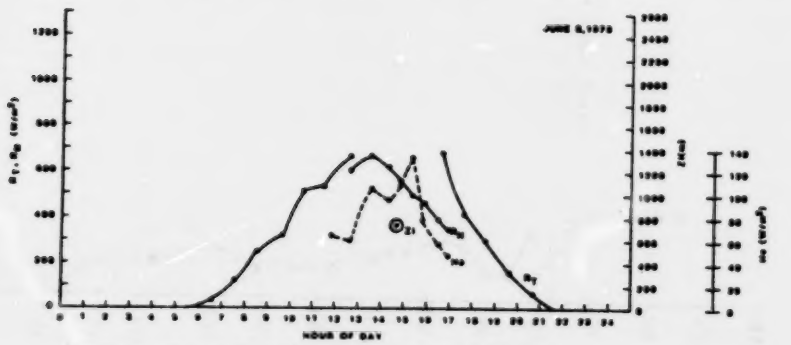


Figure 5: Diurnal Variation of Meteorological Parameters (June 8, 1978)

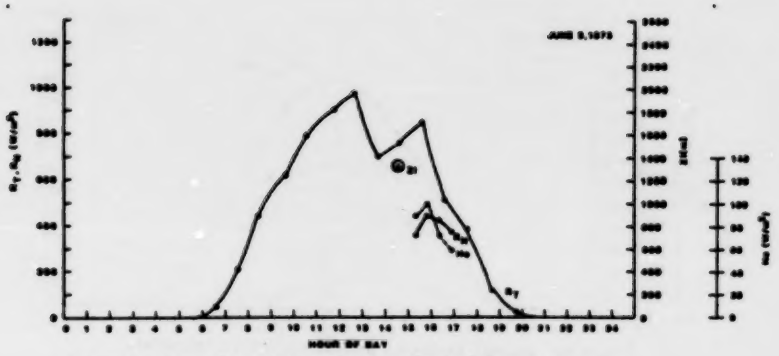


Figure 6: Diurnal Variation of Meteorological Parameters (June 9, 1978)

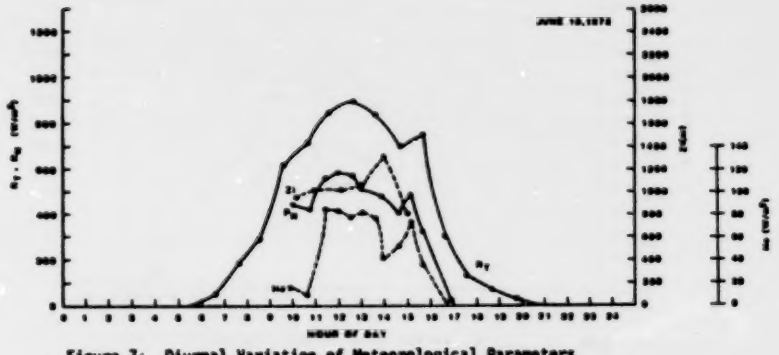


Figure 7: Diurnal Variation of Meteorological Parameters (June 10, 1978)

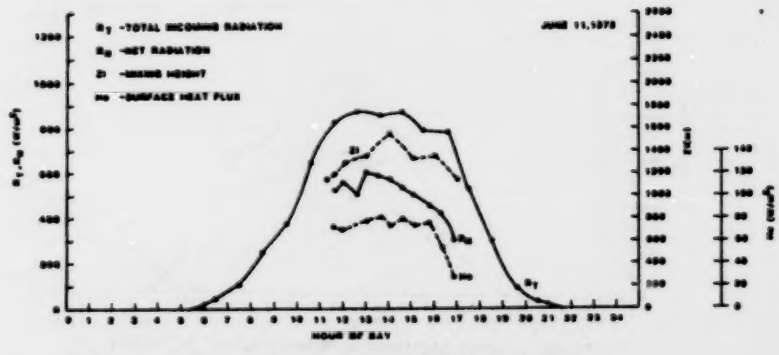


Figure 8: Diurnal Variation of Meteorological Parameters (June 11, 1978)

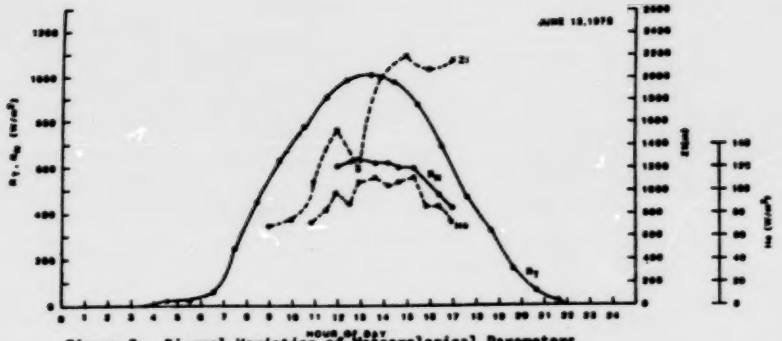


Figure 9: Diurnal Variation of Meteorological Parameters (June 13, 1978)

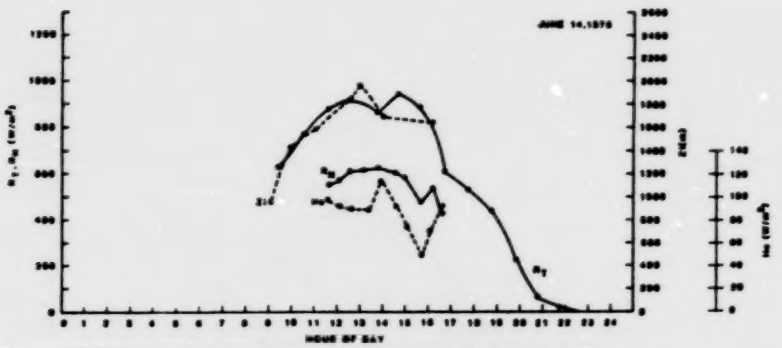


Figure 10: Diurnal Variation of Meteorological Parameters (June 14, 1978)

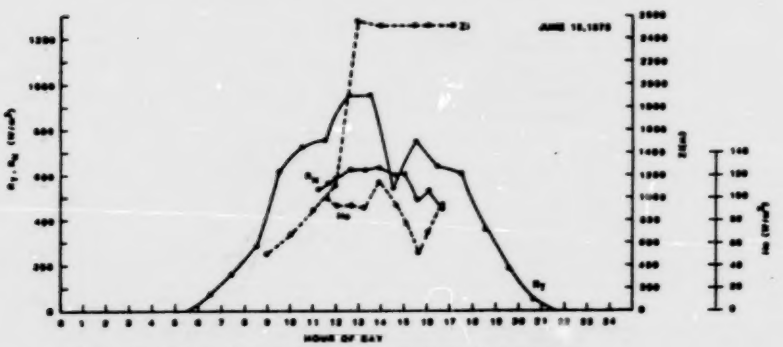


Figure 11: Diurnal Variation of Meteorological Parameters (June 15, 1978)

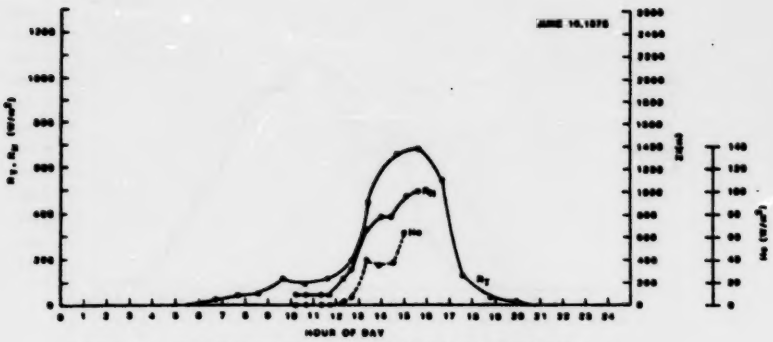


Figure 12: Diurnal Variation of Meteorological Parameters (June 16, 1978)

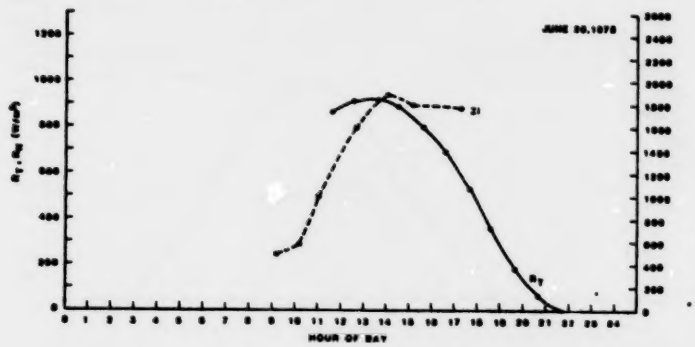


Figure 13: Diurnal Variation of Meteorological Parameters (June 20, 1978)

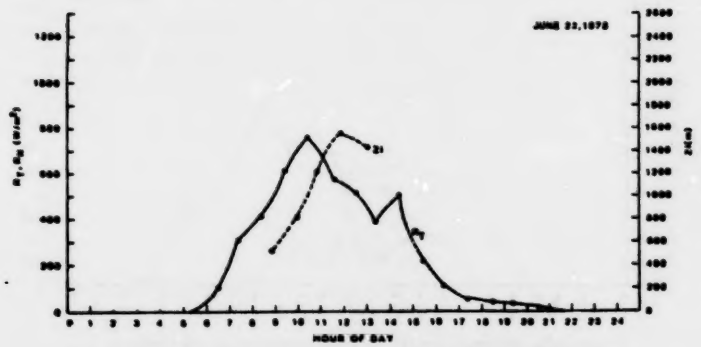


Figure 14: Diurnal Variation of Meteorological Parameters (June 22, 1978)

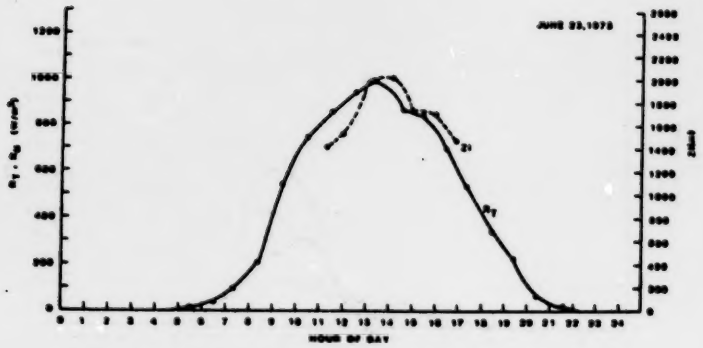


Figure 15: Diurnal Variation of Meteorological Parameters (June 23, 1978)

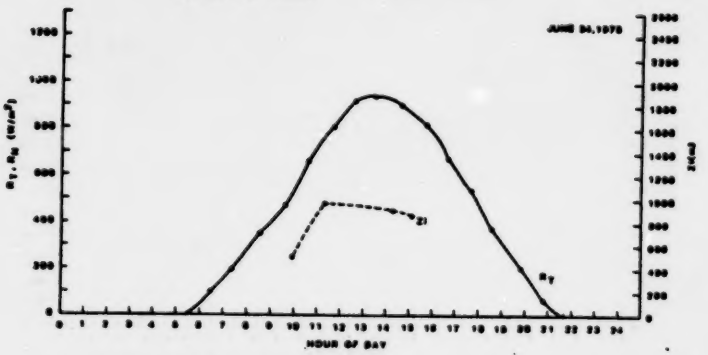


Figure 16: Diurnal Variation of Meteorological Parameters (June 24, 1978)

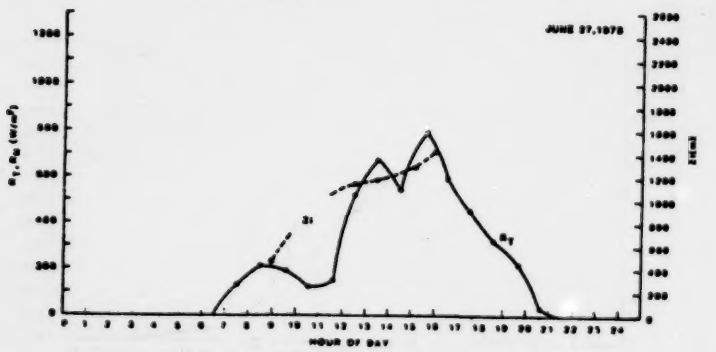


Figure 17: Diurnal Variation of Meteorological Parameters (June 27, 1978)

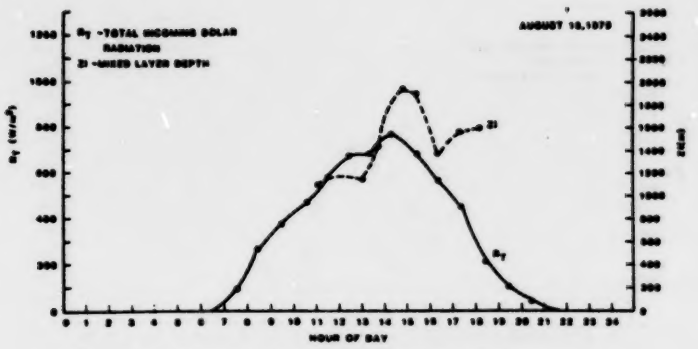


Figure 18: Diurnal Variation of Meteorological Parameters (August 16, 1979)

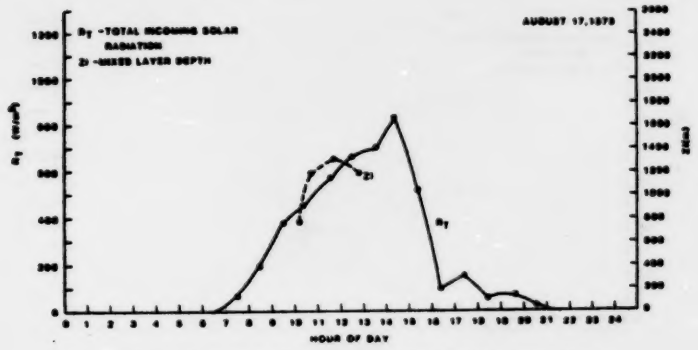


Figure 19: Diurnal Variation of Meteorological Parameters (August 17, 1979)

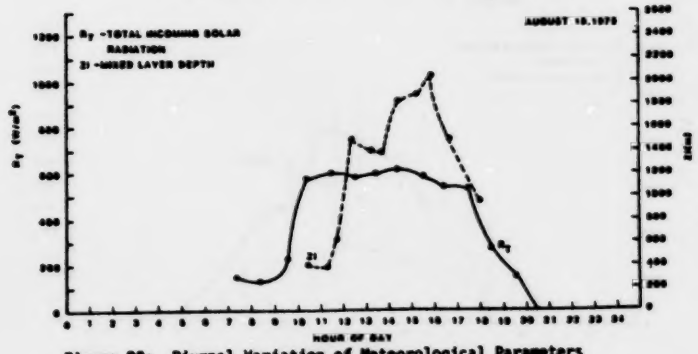


Figure 20: Diurnal Variation of Meteorological Parameters (August 19, 1979)

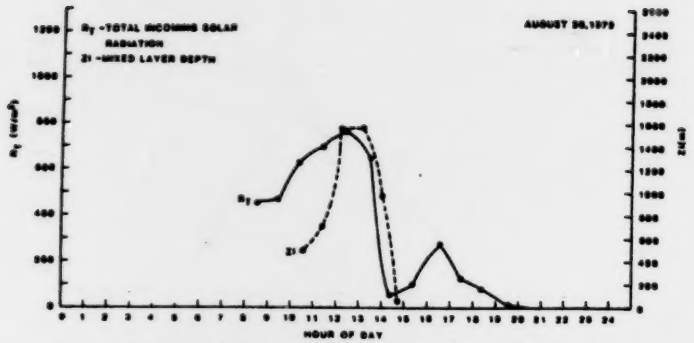


Figure 21: Diurnal Variation of Meteorological Parameters (August 20, 1979)

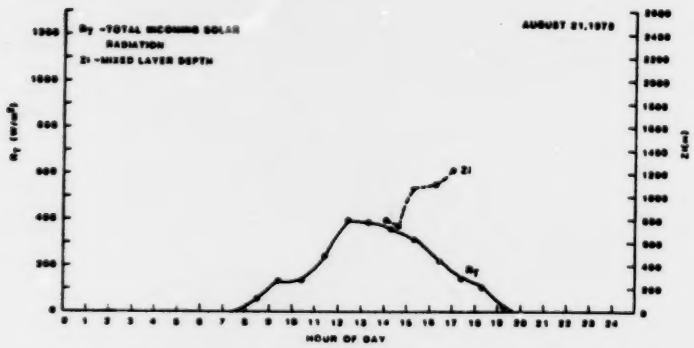


Figure 22: Diurnal Variation of Meteorological Parameters (August 21, 1979)

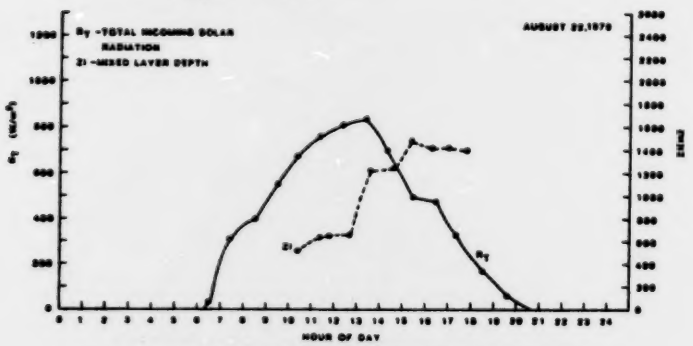


Figure 23: Diurnal Variation of Meteorological Parameters (August 22, 1979)

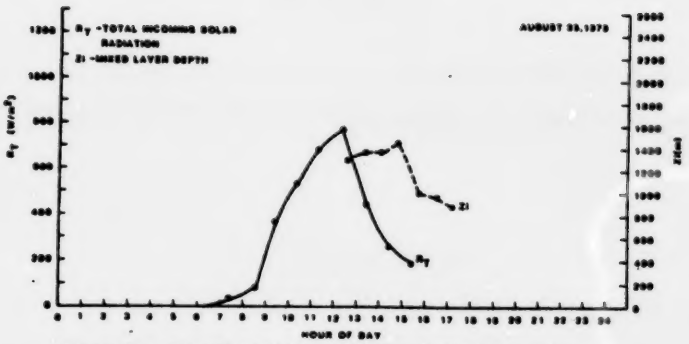


Figure 24: Diurnal Variation of Meteorological Parameters (August 25, 1979)

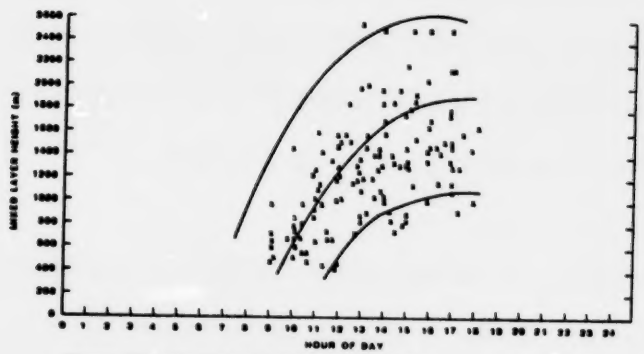


Figure 25: Mixed Layer Height versus Time (June 1978 and August 1979 data)

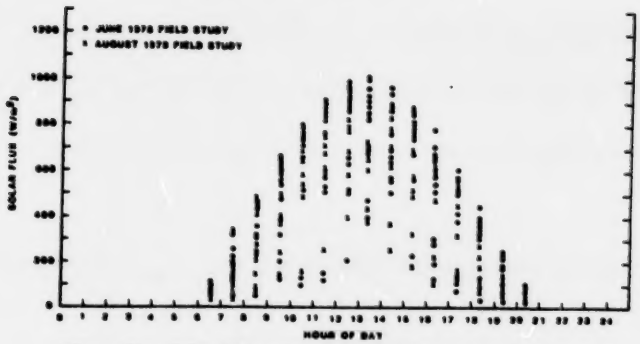


Figure 26: Solar Flux versus Time of Day (June 1978 and August 1979 data combined)

APPENDIX 1

Using Temperature Measurements to Predict Surface Heat Flux

A. Venkatram

Under convective conditions the plume dispersion parameters σ_y and σ_z can be written as

$$\sigma_y = \sigma_w \; t \; f_y(t/T_L) \; ; \sigma_z = \sigma_w \; t \; f_z(t/T_L) \qquad (1)$$

In (1), σ_w is the standard deviation vertical velocity fluctuation, t=x/u where u is the mean velocity, t is the time of plume travel, and T_L is the Lagrangian intergral time scale. At the short distances where high concentrations occur, it is possible to neglect the dependence of f_y and f_z on T_L. Thus, measurements of σ_y and σ_z together with σ_w and u will enable us to derive the functions f_y and f_z. Once σ_y and σ_z are known, we can predict $f_{y,z}$ if we can estimate σ_w.

Direct measurements of σ_w at the levels at which elevated stacks emit pollutants poses serious experimental problems, and it is better to infer σ_w through a more easily measured variable. Under convective conditions, this indirect measurement of σ_w is quite reliable because of the simple relationship between σ_w and σ_T, the standard deviation of temperature fluctuations. We note that σ_T is a scalar variable which can be measured with relatively simple instrumentation.

It can be shown that under unstable conditions σ_T and σ_w can be written as

$$\sigma_w = A\left(\frac{g\,H_o\,Z}{T}\right)^{1/3}; \quad \sigma_T = B\,H_o^{2/3}\left(\frac{g\,Z}{T}\right)^{-1/3} \qquad (2)$$

where A = 1.33 and B = 1.35. In (2) H_o is the surface heat flux and T is the average temperature of the CBL. Form (2) we see that

$$\sigma_w = 1.14\left(\frac{\sigma_T\,g\,Z}{T}\right)^{1/2} \qquad (3)$$

It is worthwhile to point out that above $Z > 0.1 Z_i$, σ_w can be assumed to be constant (Z_i is the mixed layer height). From (3) we see that measurement of σ_T with a fast response thermometer will enable use to estimate σ_w and thus σ_y and σ_z.

We note from (2) that H_o is the only unknown in the formula for σ_w. It is clear than σ_T allows us to compute H_o from the equation.

$$H_o = (\sigma_T/B)^{3/2} \quad (gZ/T)^{1/2} \qquad (4)$$

Thus, in effect σ_T is a surrogate for H_o. In order to be able to predict σ_w, we need to relate H_o computed from (4) to an operational available variable such as insolation (incoming solar flux). Simultaneous measurements of solar flux and σ_T will then permit us to establish this relationship. Then, it is a simple matter to predict σ_y and σ_z and thus the pollutant concentration if we have a reasonable estimate of the incoming solar flux.

It is useful to point out that a direct measurement of H_o with some sort of $\overline{w' \theta'}$ device would be extremely useful in checking (4). However, direct measurement of H_o is less than completely reliable, and probably no more accurate than that inferred from (4). Thus, a comparison of H_o from (4) with H_o from $\overline{w'\theta'}$ measurement would be more a test of consistency than accuracy of the proposed method.

Appendix 2

June 1978 and August 1979 Meteorological Data

Section A-2.1:

Plots of wind speed, wind direction and ambient temperature versus height are presented for June 1980.

Section A-2.2:

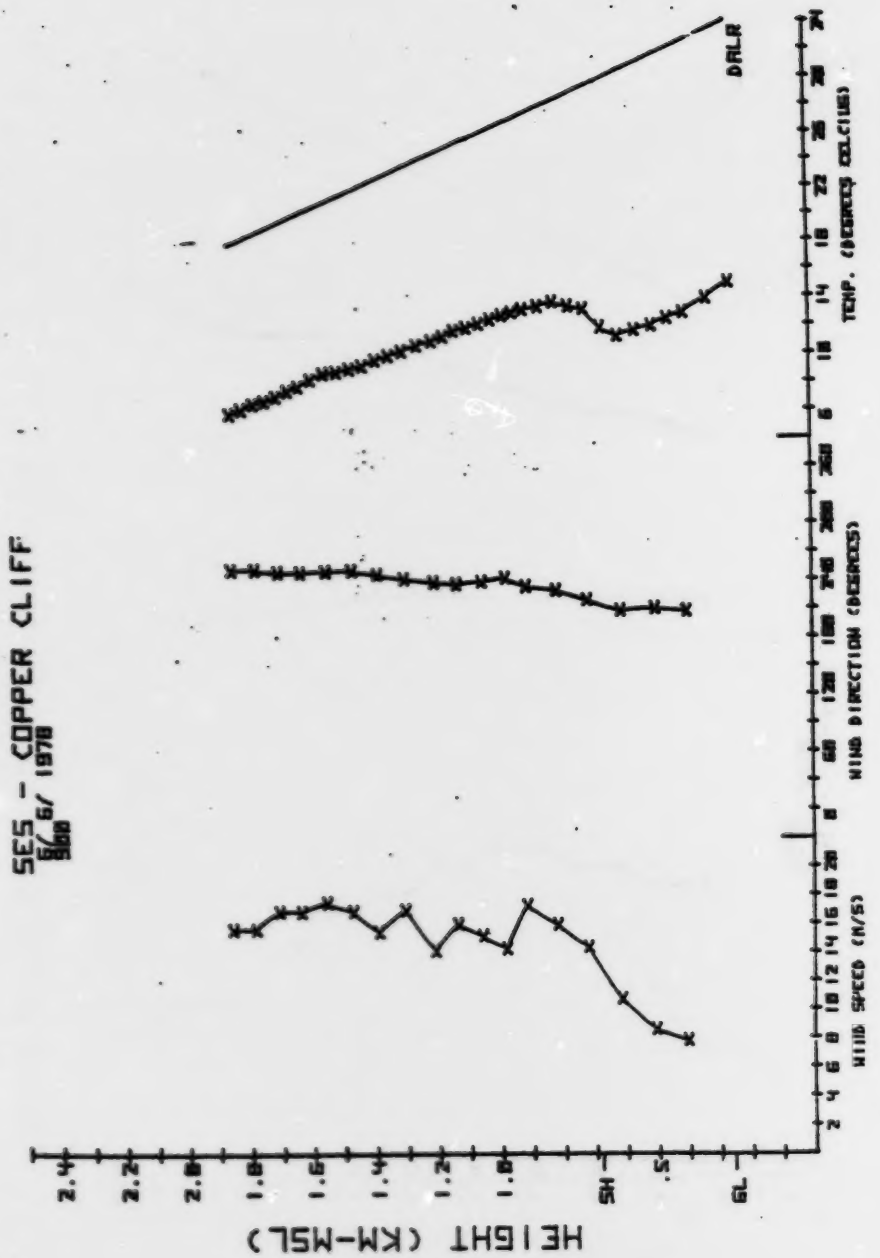
Plots of potential temperature versus height are presented consecutively for selected days in June 1978.

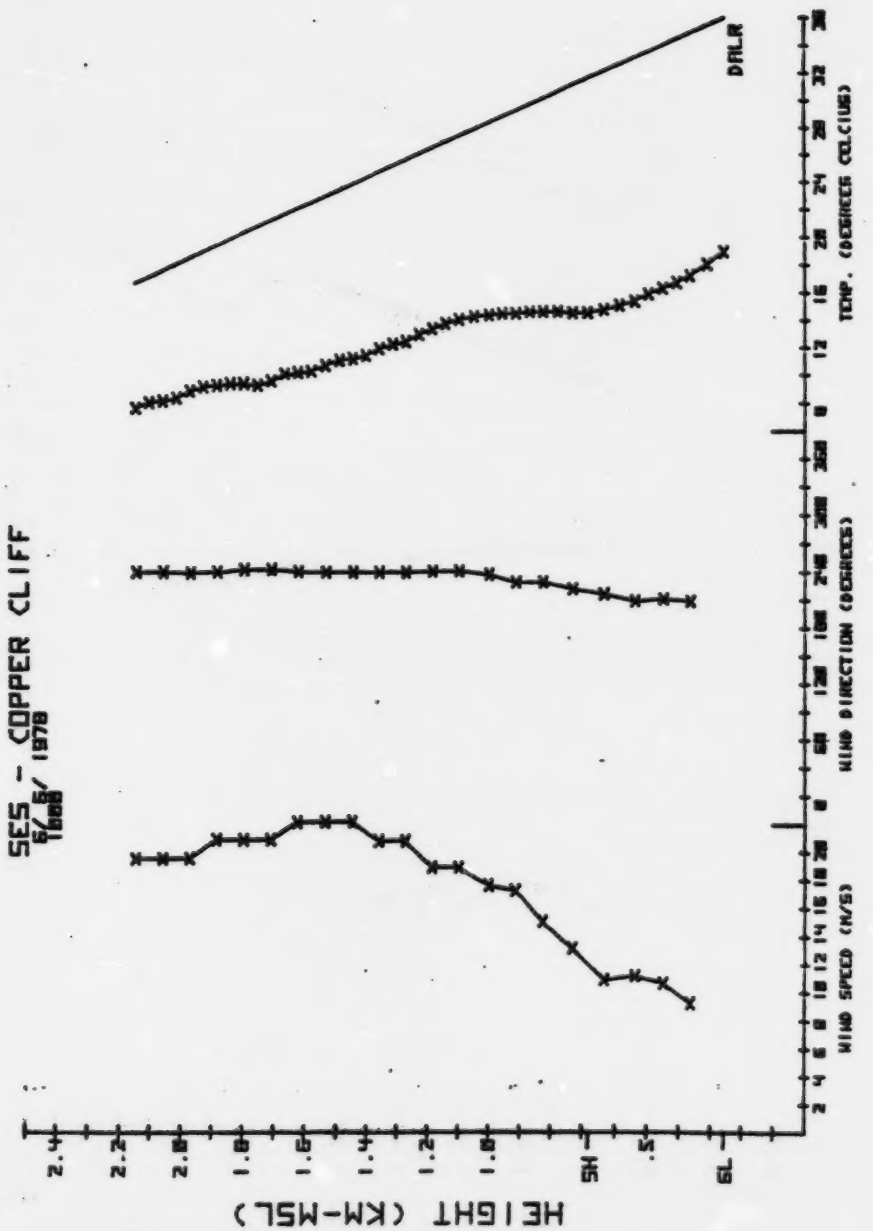
Section A-2.3:

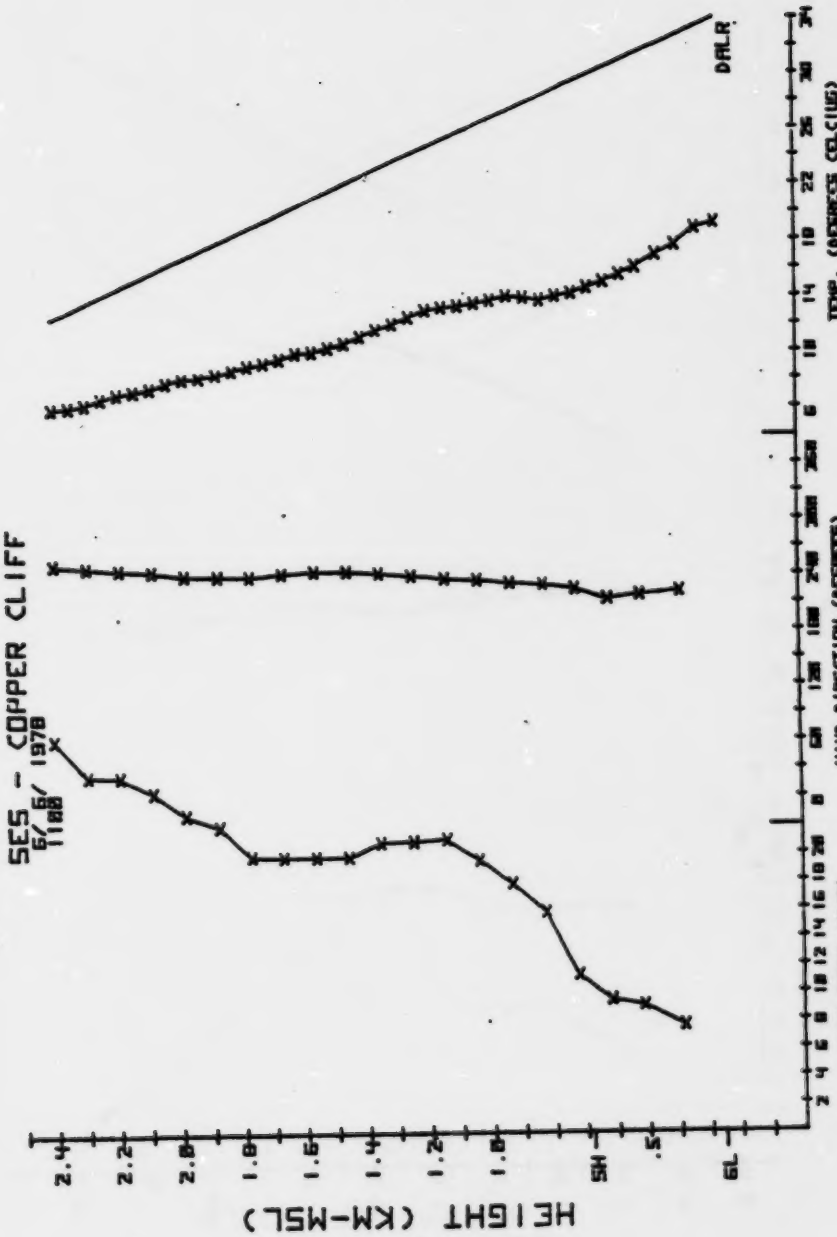
Plots of wind speed, wind direction and potential temperature versus height are presented for August 1979.

WC/kr 6/TDA1

SECTION A.2.1


SES - COPPER CLIFF
6/6/ 1978
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
SH
GL
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
TEMP. (DEGREES CELCIUS)
DALR


SES - COPPER CLIFF
6/6/ 1978
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
SH
SL
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
TEMP. (DEGREES CELCIUS)
DALR


SES - COPPER CLIFF
6/6/ 1978
1188
HEIGHT (KM-MSL)
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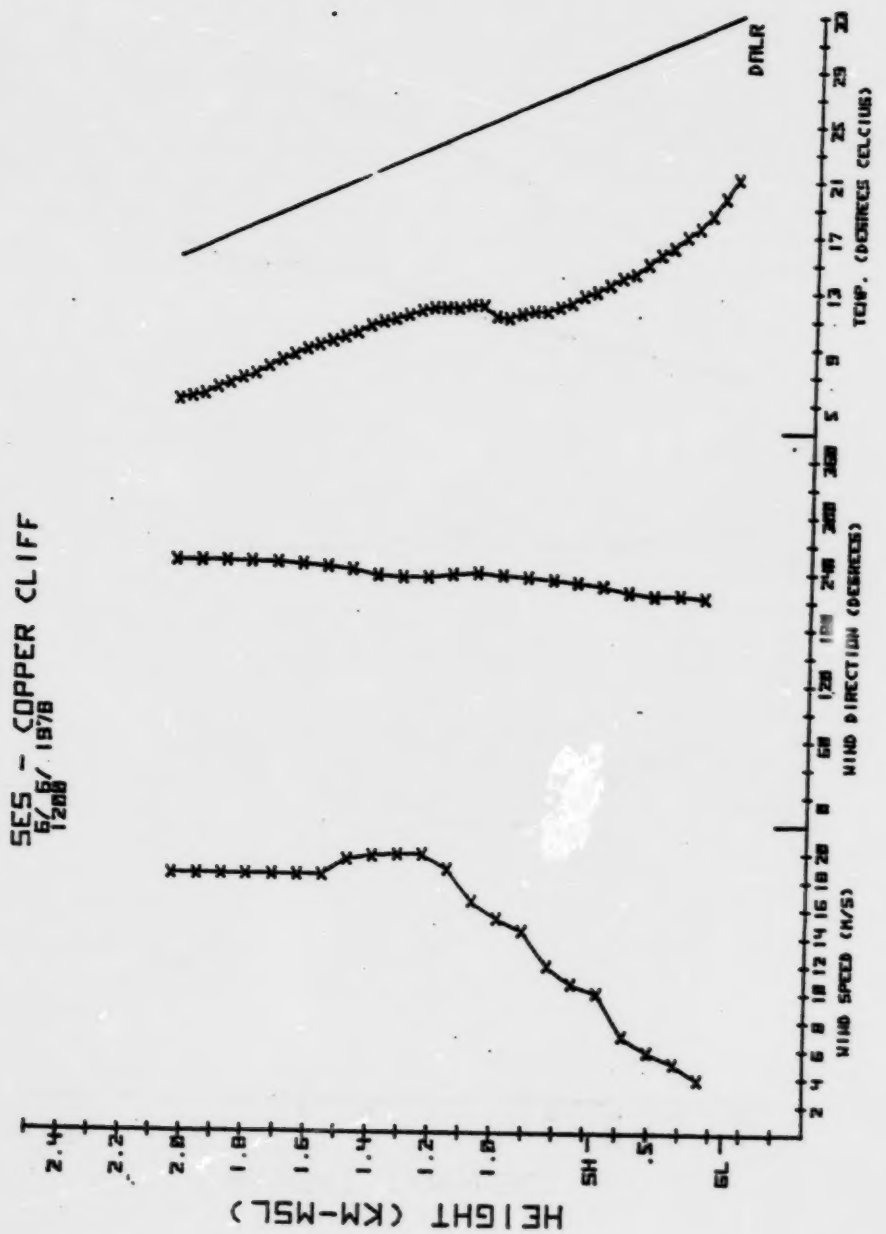
2.0
1.8
1.6
1.4
1.2
1.0
.5
SH
SL
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
TEMP. (DEGREES CELCIUS)
DALR


SES - COPPER CLIFF
6/6/ 1978
1200
HEIGHT (KM-MSL)
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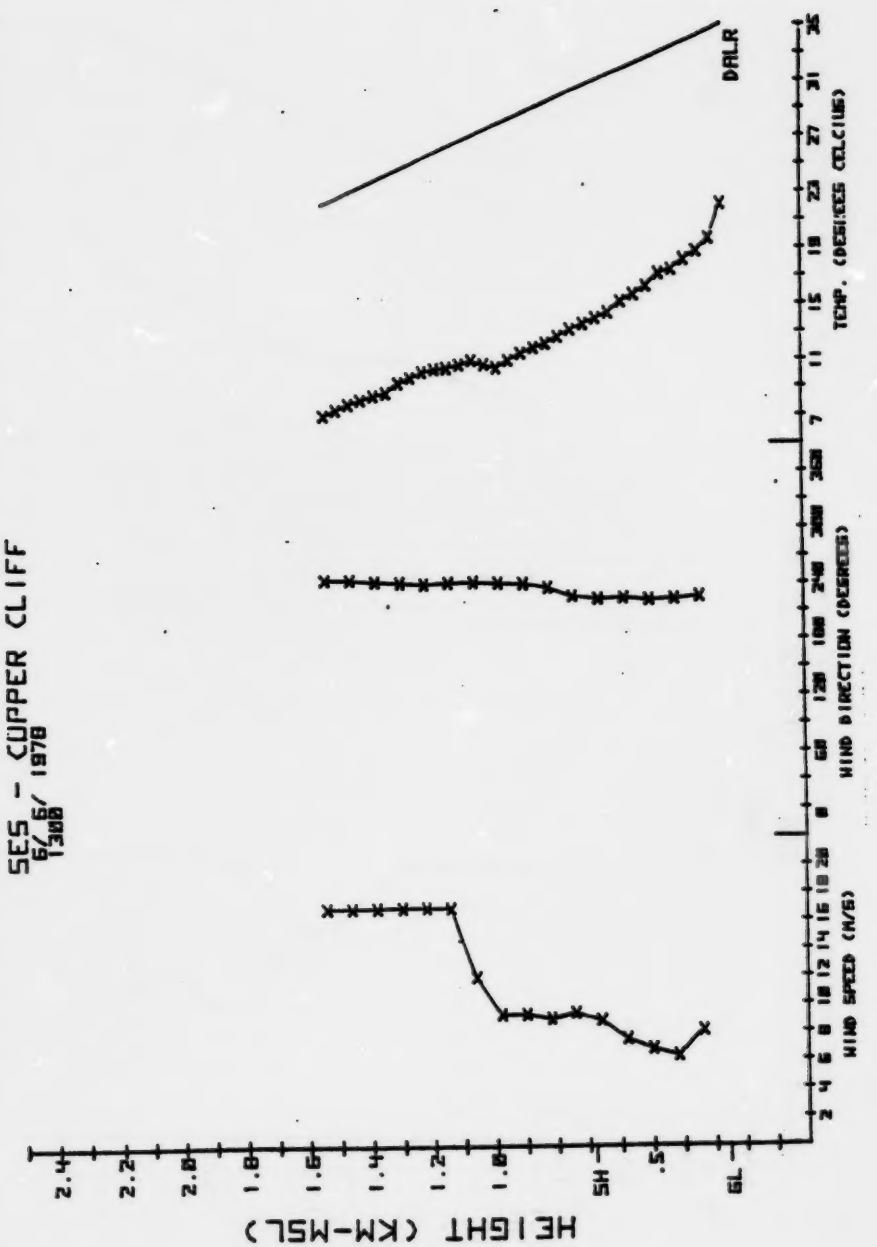
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.5
SH
SL
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
TEMP. (DEGREES CELCIUS)
DALR


SES - CUPPER CLIFF
67/6/ 1978
1300
HEIGHT (KM-MSL)
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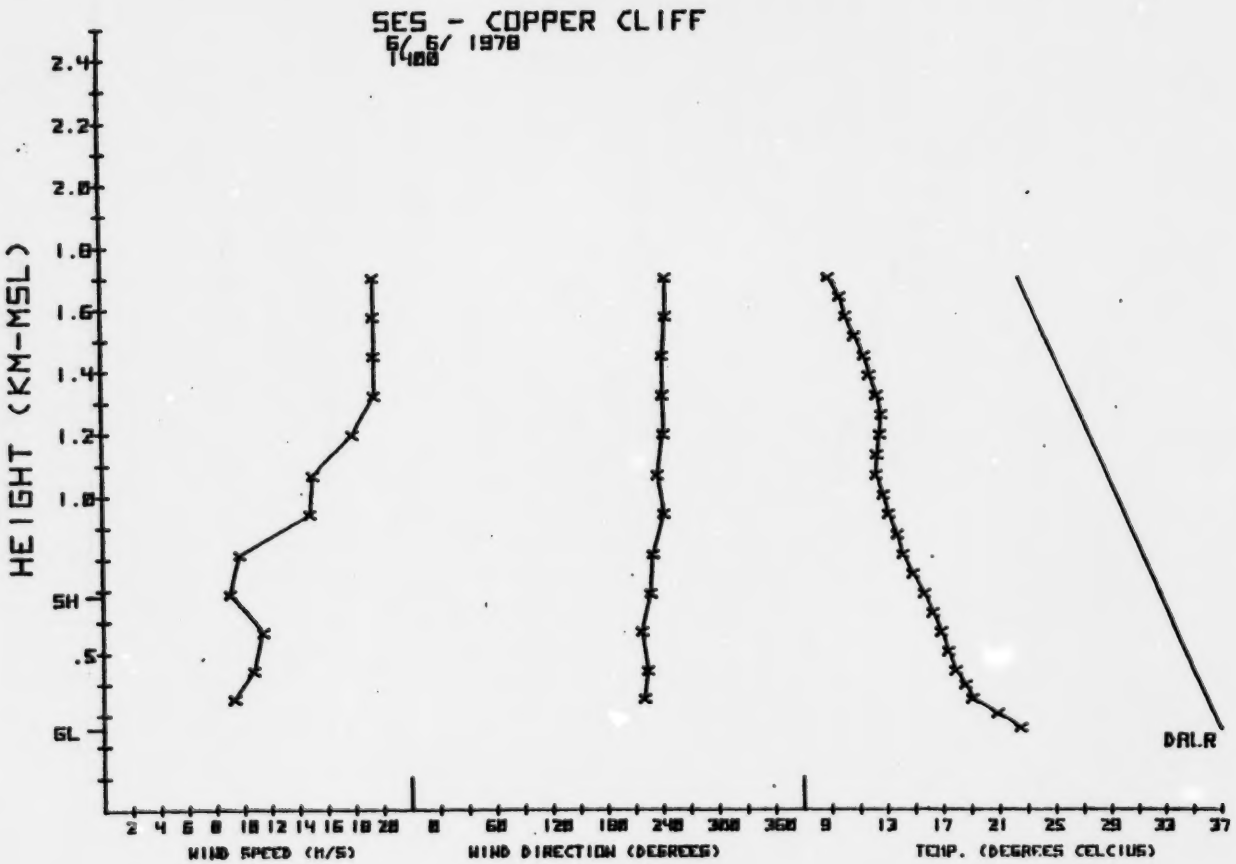
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.5
HS
GL
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
TEMP. (DEGREES CELCIUS)
DALR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6/ 6/ 1978
1400
HEIGHT (KM-MSL)
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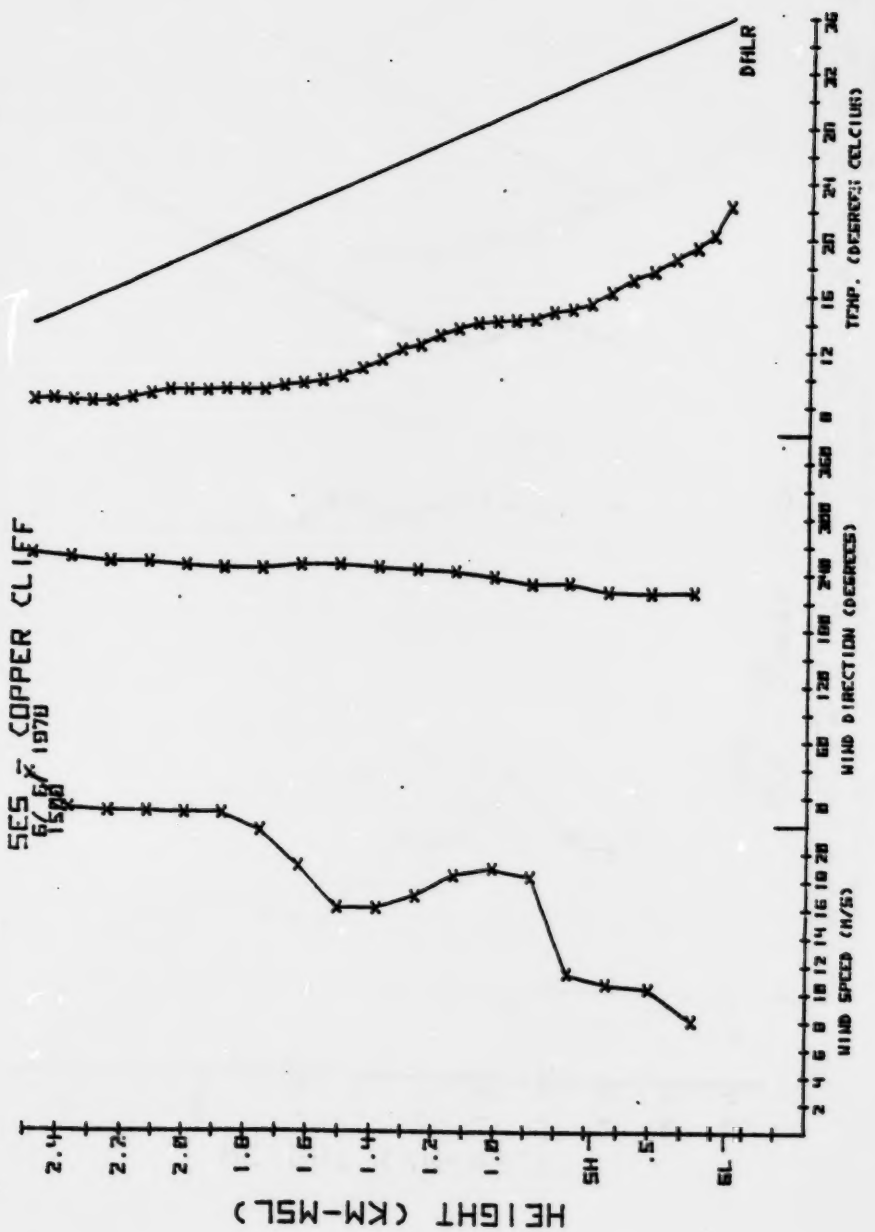
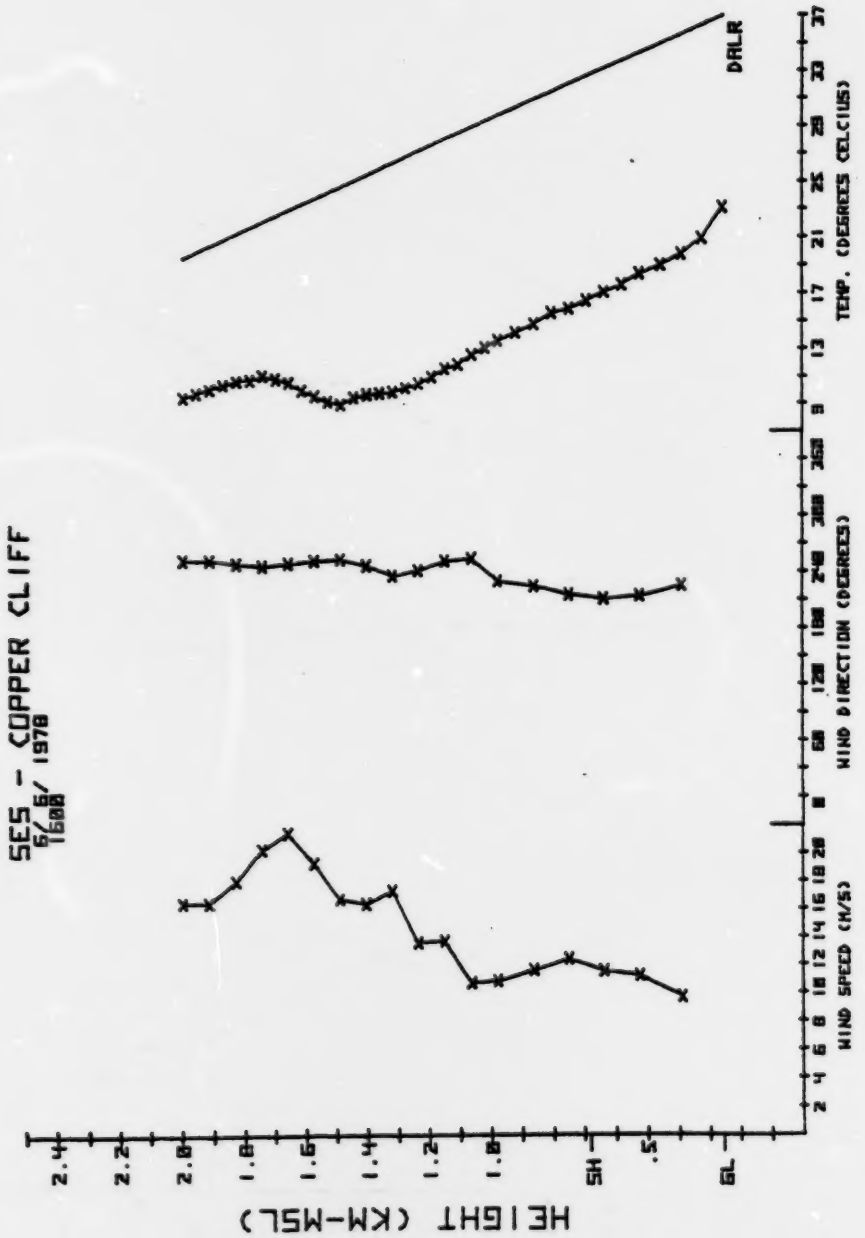
2.0
1.8
1.6
1.4
1.2
1.0
SH
.5
GL
DRLR
2 4 6 8 10 12 14 16 18 20
WIND SPEED (M/S)
0 60 120 180 240 300 360
WIND DIRECTION (DEGREES)
9 13 17 21 25 29 33 37
TEMP. (DEGREES CELCIUS)


SES - COPPER CLIFF
1978
HEIGHT (KM-MSL)
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
TEMP. (DEGREES CELCIUS)
DALR
TL
ML
HL


SES - COPPER CLIFF
6/6/ 1978
1600
HEIGHT (KM-MSL)
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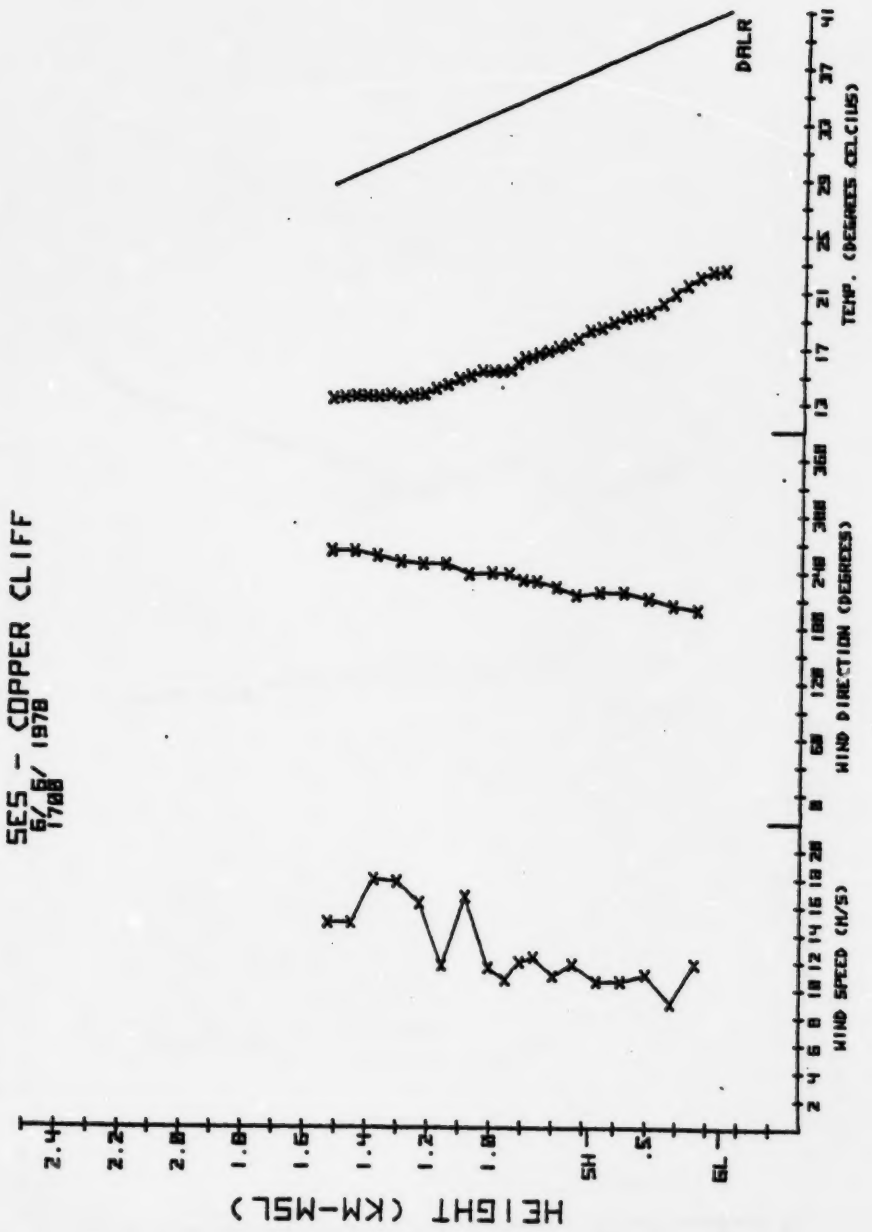
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.5
HS
GL
WIND SPEED (M/S)
2 4 6 8 10 12 14 16 18 20
WIND DIRECTION (DEGREES)
0 60 120 180 240 300 360
TEMP. (DEGREES CELCIUS)
5 13 17 21 25 29 33 37
DALR


SES - COPPER CLIFF
6/6/ 1978
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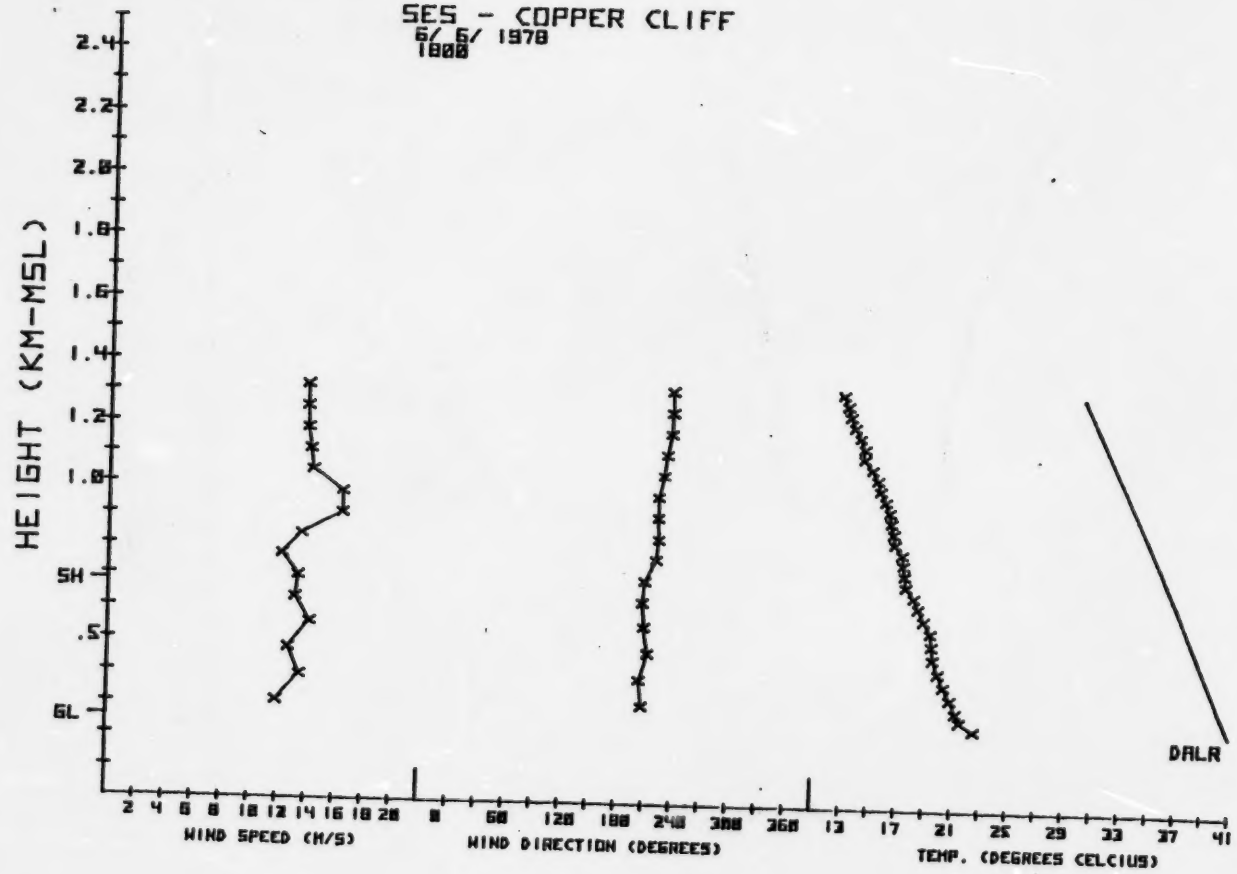
2.0
1.8
1.6
1.4
1.2
1.0
.5
HS
GL
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
TEMP. (DEGREES CELCIUS)
DALR


SES - COPPER CLIFF
6/ 6/ 1978
1800
HEIGHT (KM-MSL)
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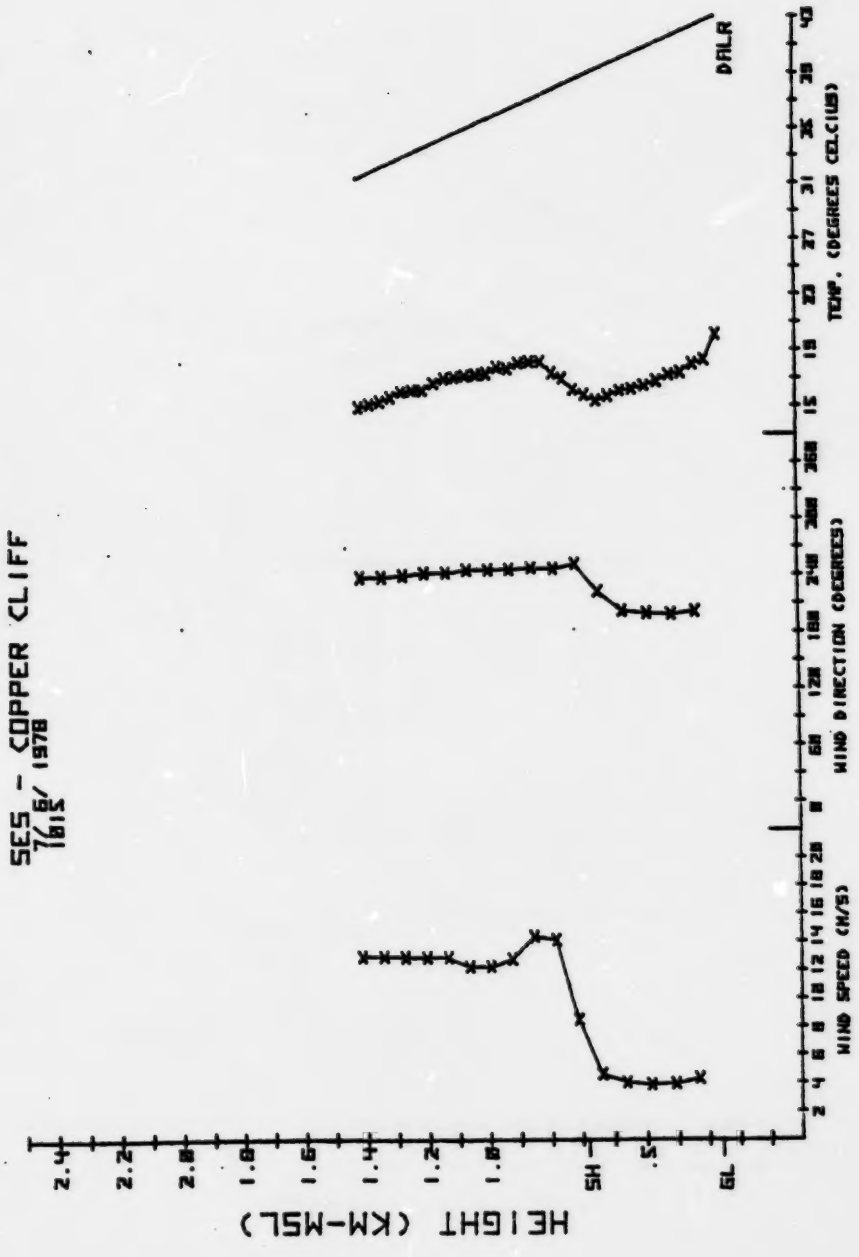
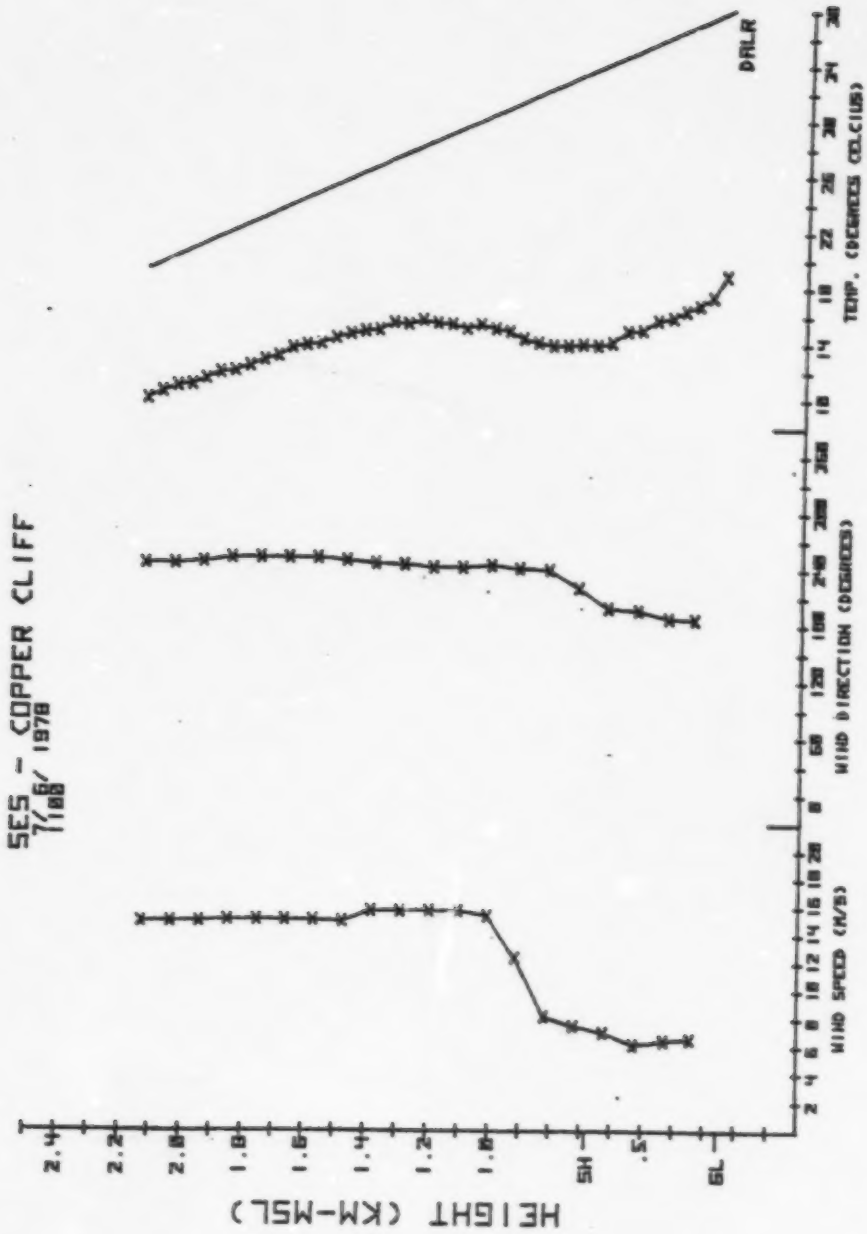
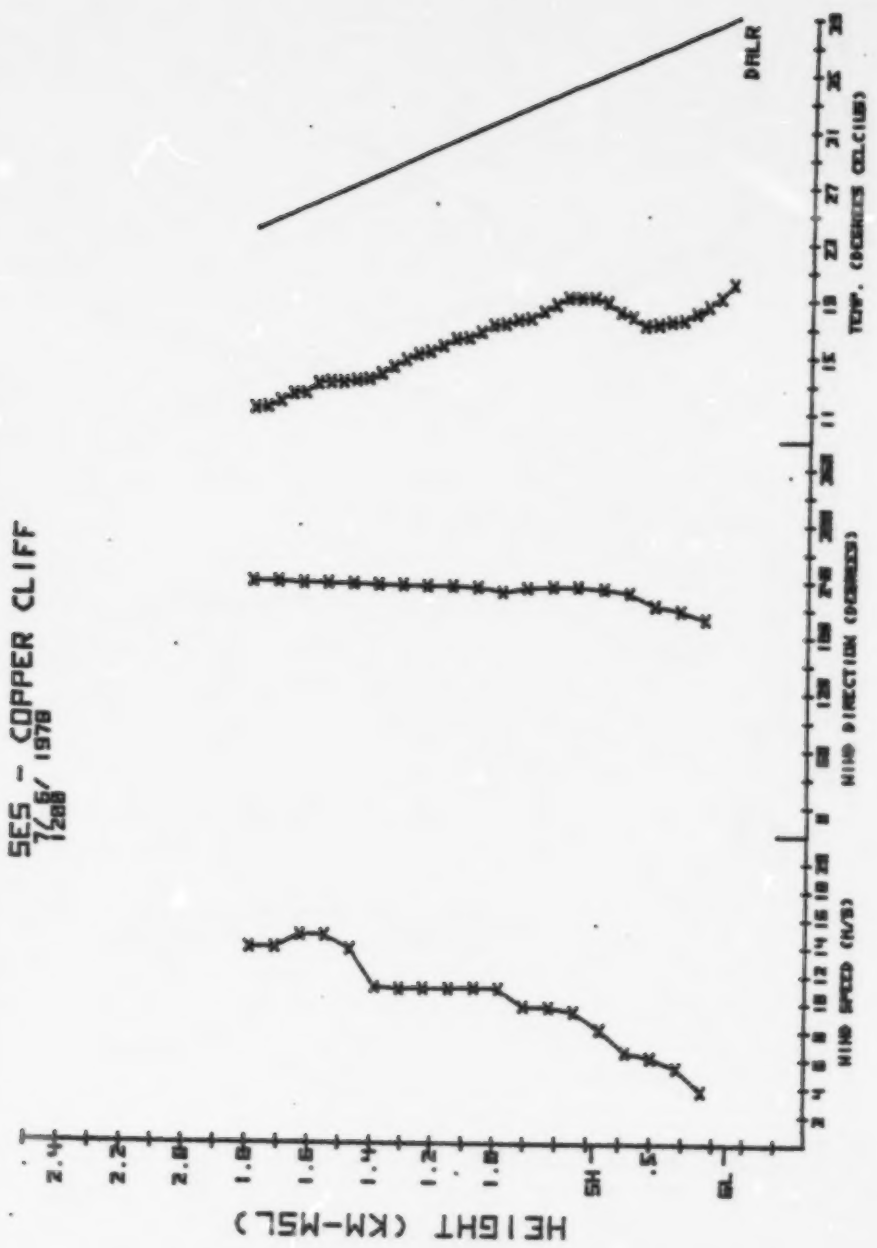
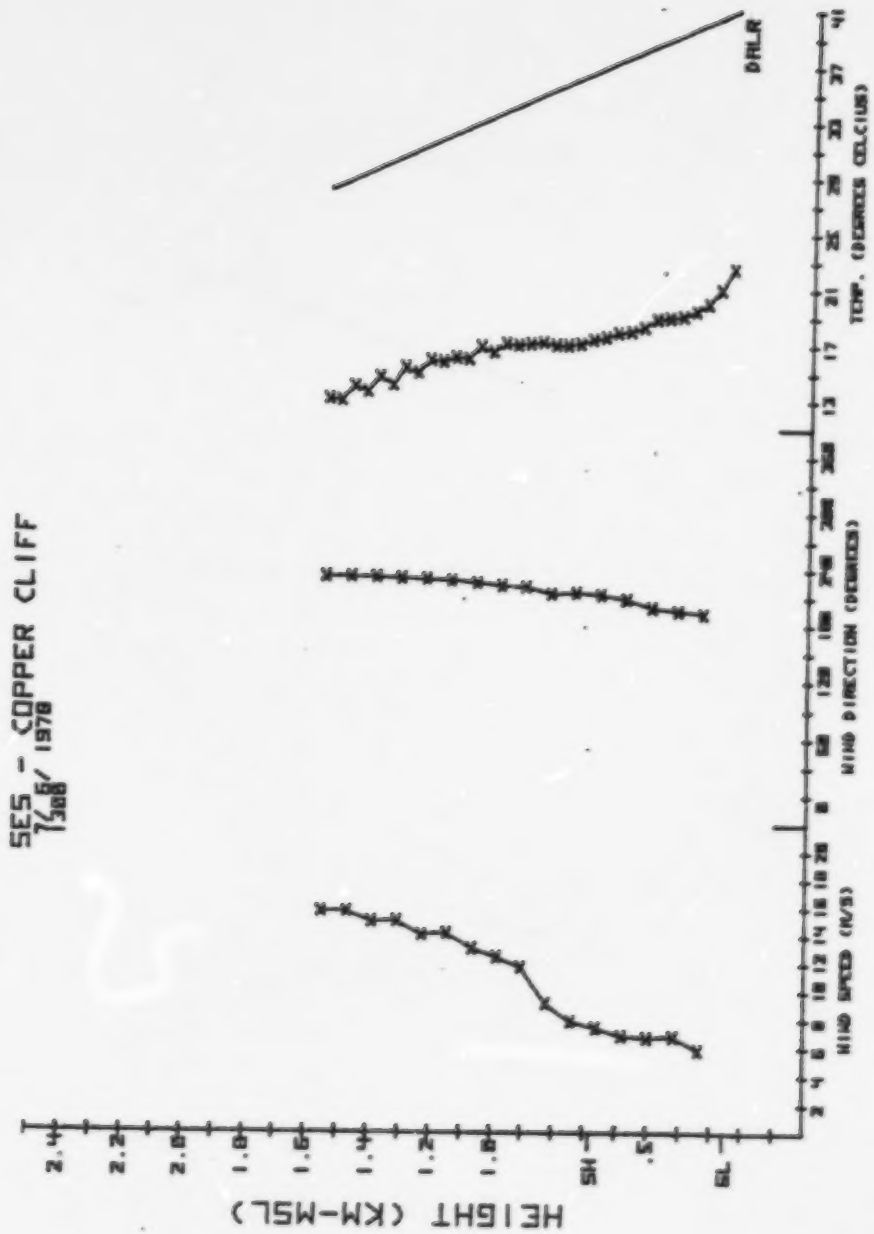
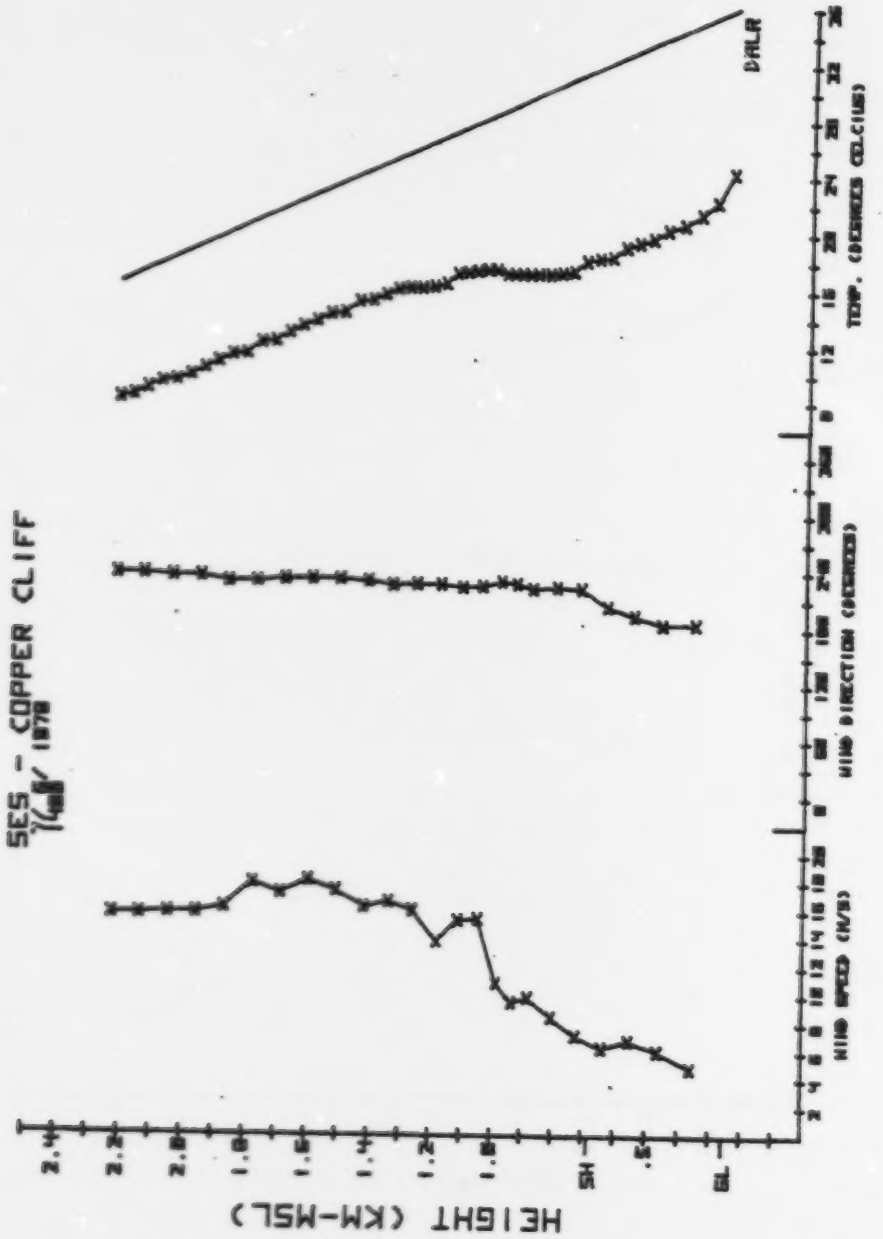
2.2
2.0
1.8
1.6
1.4
1.2
1.0
SH
.5
GL
DALR
2 4 6 8 10 12 14 16 18 20
WIND SPEED (M/S)
0 60 120 180 240 300 360
WIND DIRECTION (DEGREES)
13 17 21 25 29 33 37 41
TEMP. (DEGREES CELCIUS)

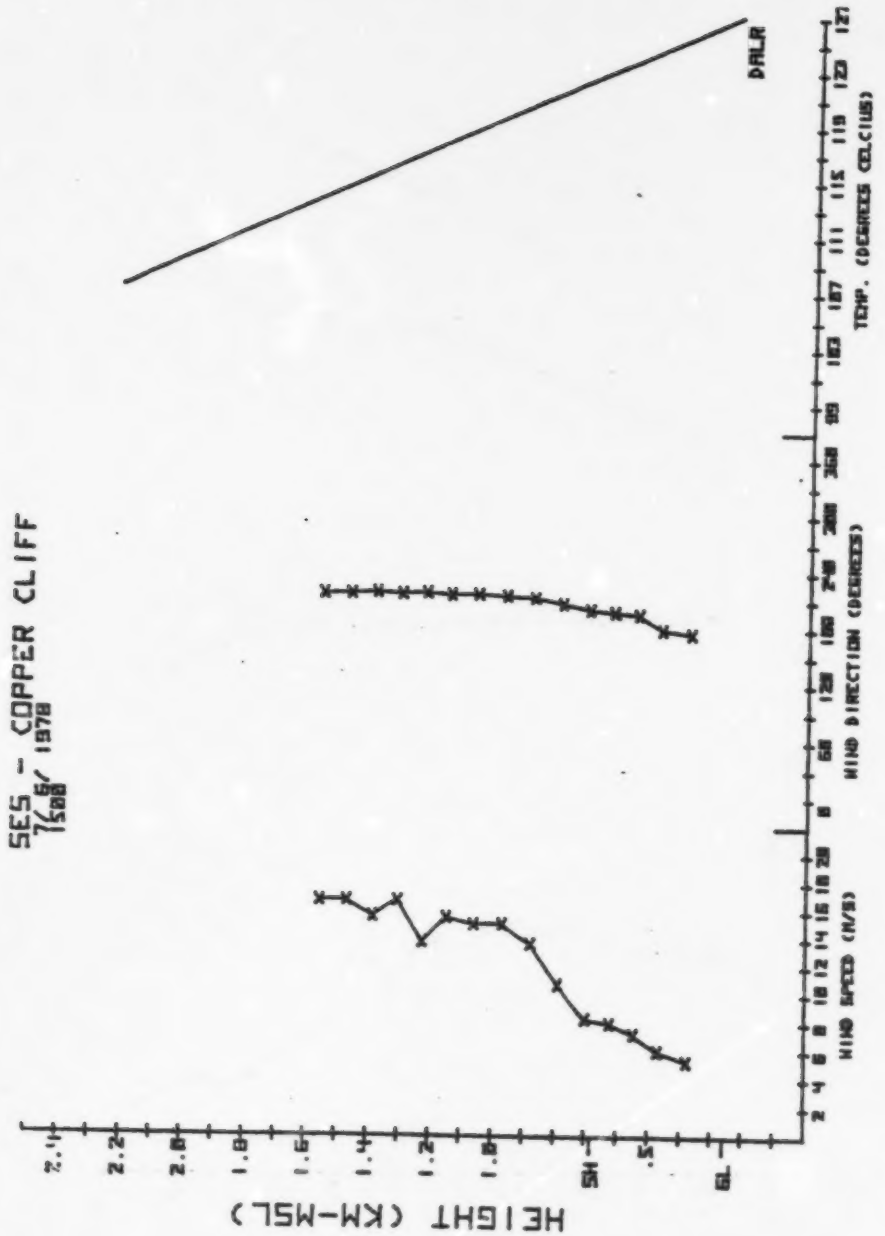

SES - COPPER CLIFF
7/8/ 1978
1815
HEIGHT (KM-MSL)
2.4
2.2
2.8
1.8
1.6
1.4
1.2
1.8
HS
.5
GL
WIND SPEED (M/S)
2 4 6 8 10 12 14 16 18 20
0
60 120 180 240 300 360
WIND DIRECTION (DEGREES)
5 10 15 20 23 27 31 35 40
TEMP. (DEGREES CELCIUS)
DALR

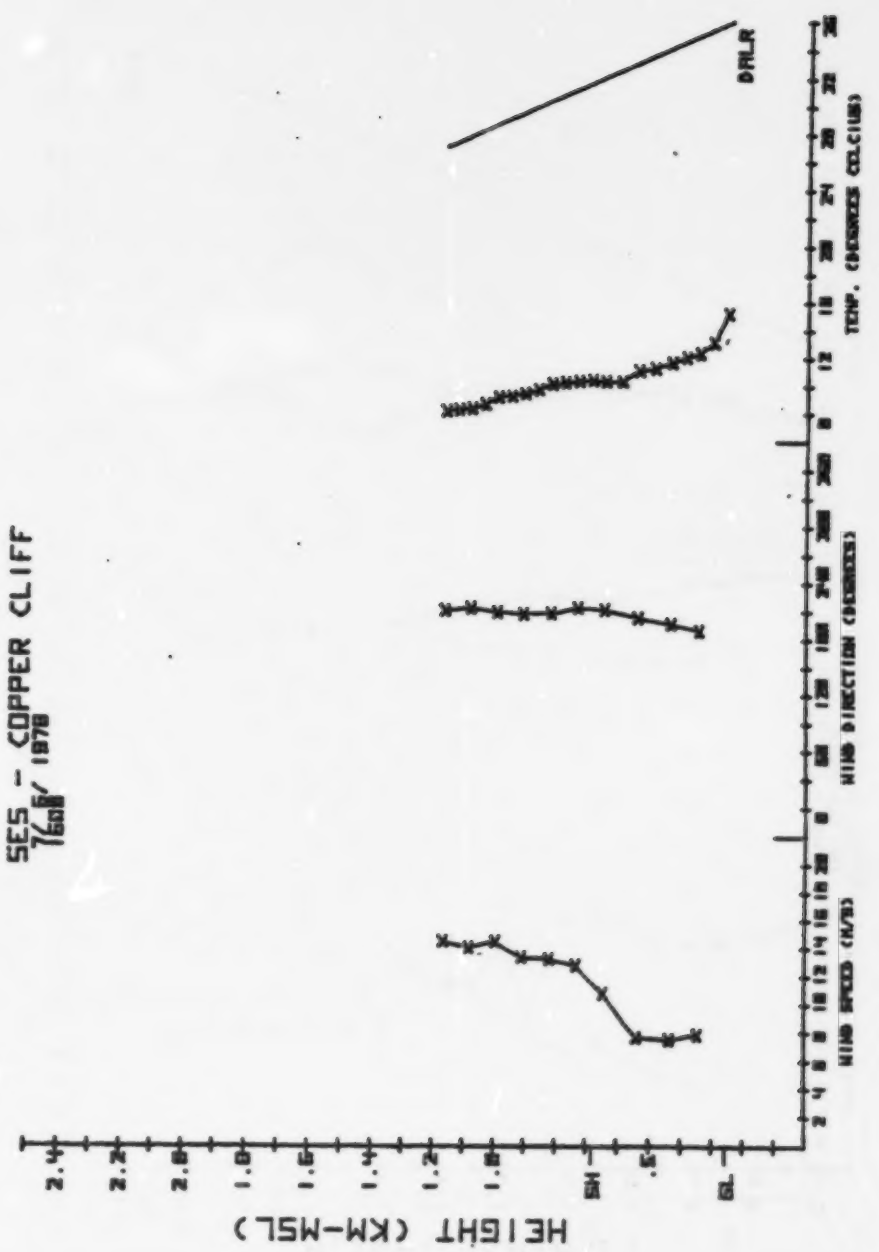

SES - COPPER CLIFF
7/08/ 1978
HEIGHT (KM-MSL)
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
TEMP. (DEGREES CELCIUS)
DALR
SH
SL

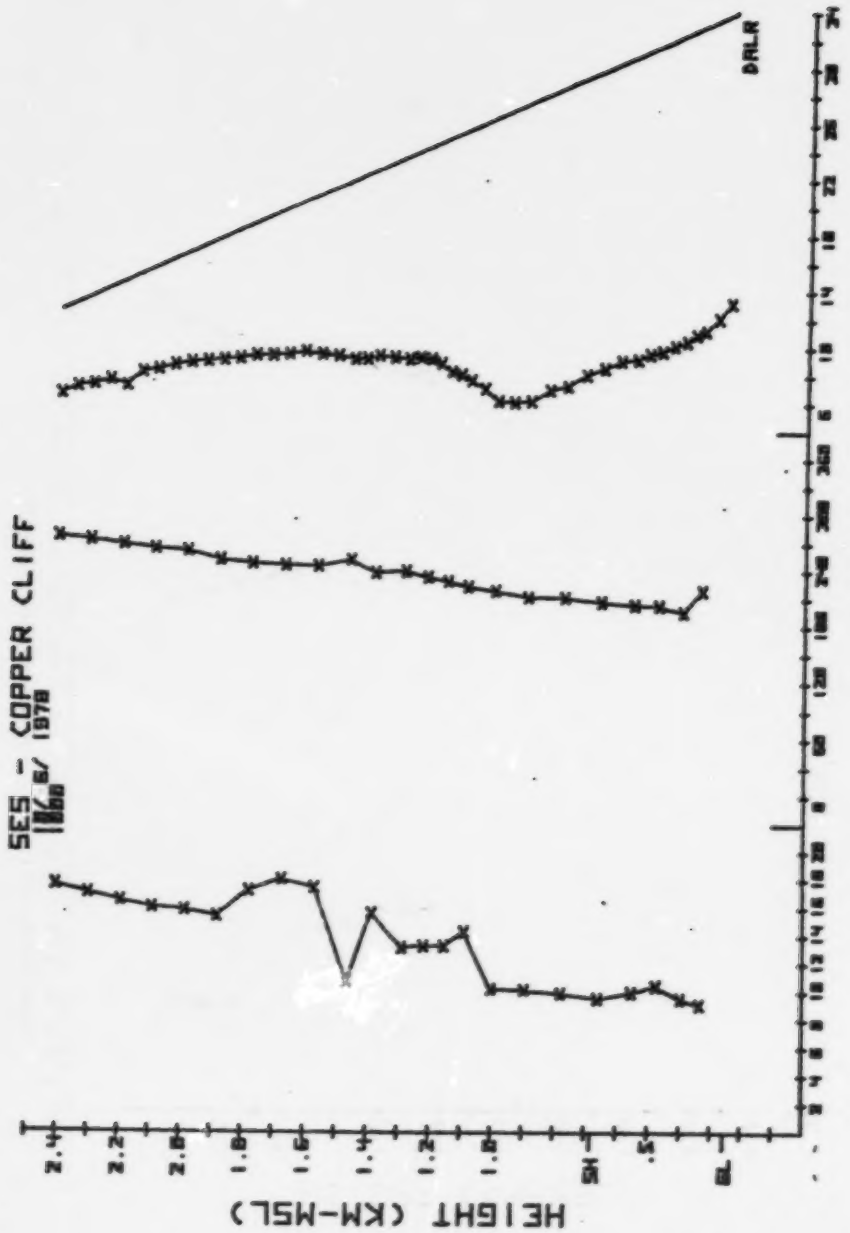

SES - COPPER CLIFF
7/6/ 1978
1288
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
SH
SL
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
TEMP. (DEGREES CELCIUS)
DALR

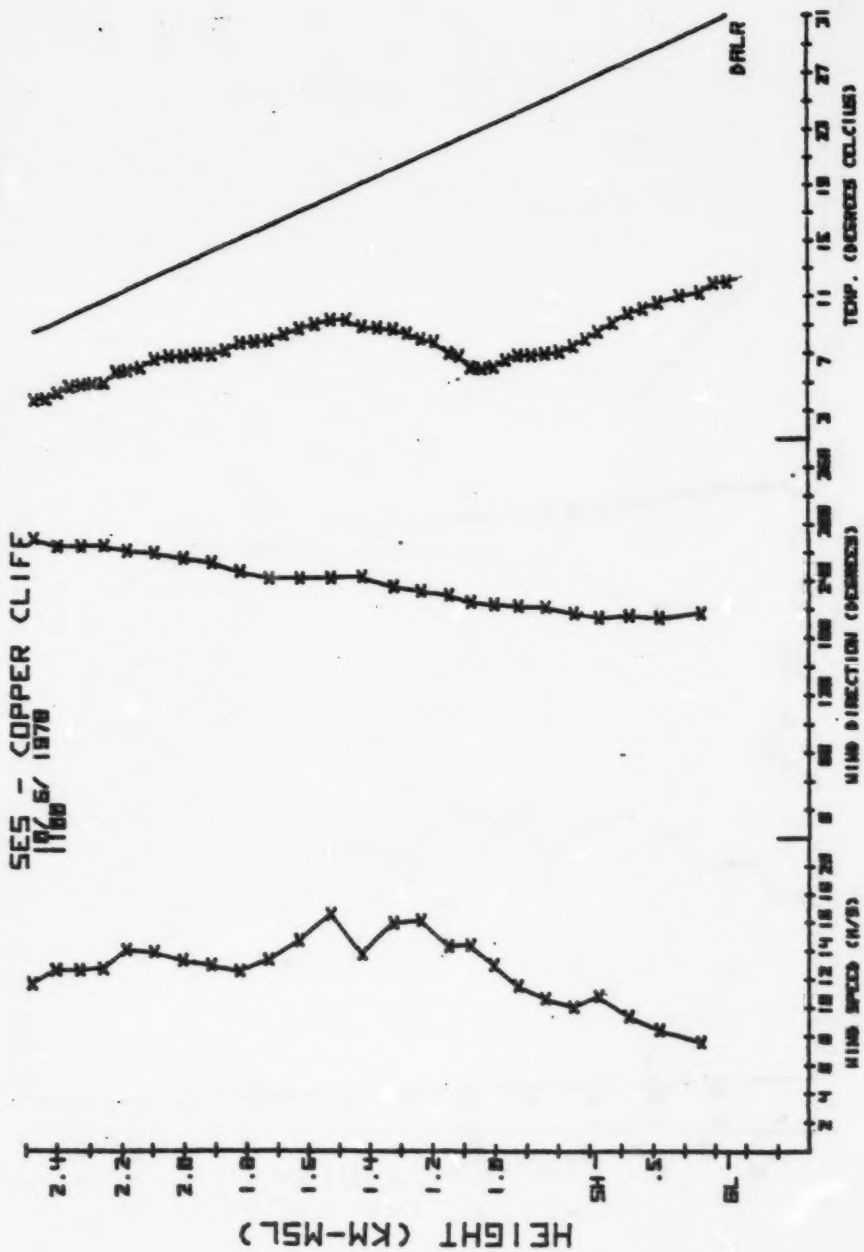

SES - COPPER CLIFF
1/6/1978
1388
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
HS
BL
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
TEMP. (DEGREES CELCIUS)
DALR

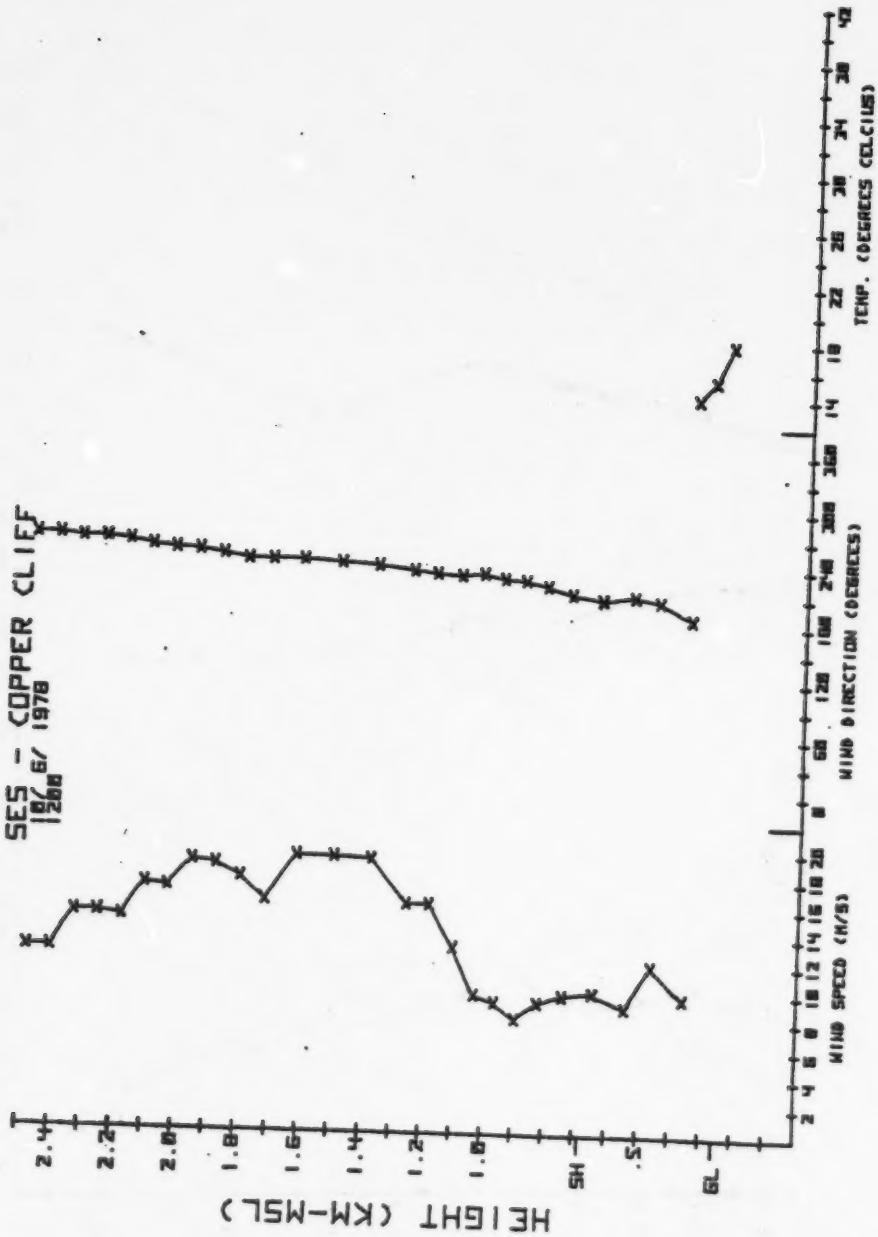

SES - COPPER CLIFF
HEIGHT (KM-MSL)
DALR
TEMP. (DEGREES CELCIUS)
WIND DIRECTION (DEGREES)
WIND SPEED (KTS)
HS
TS

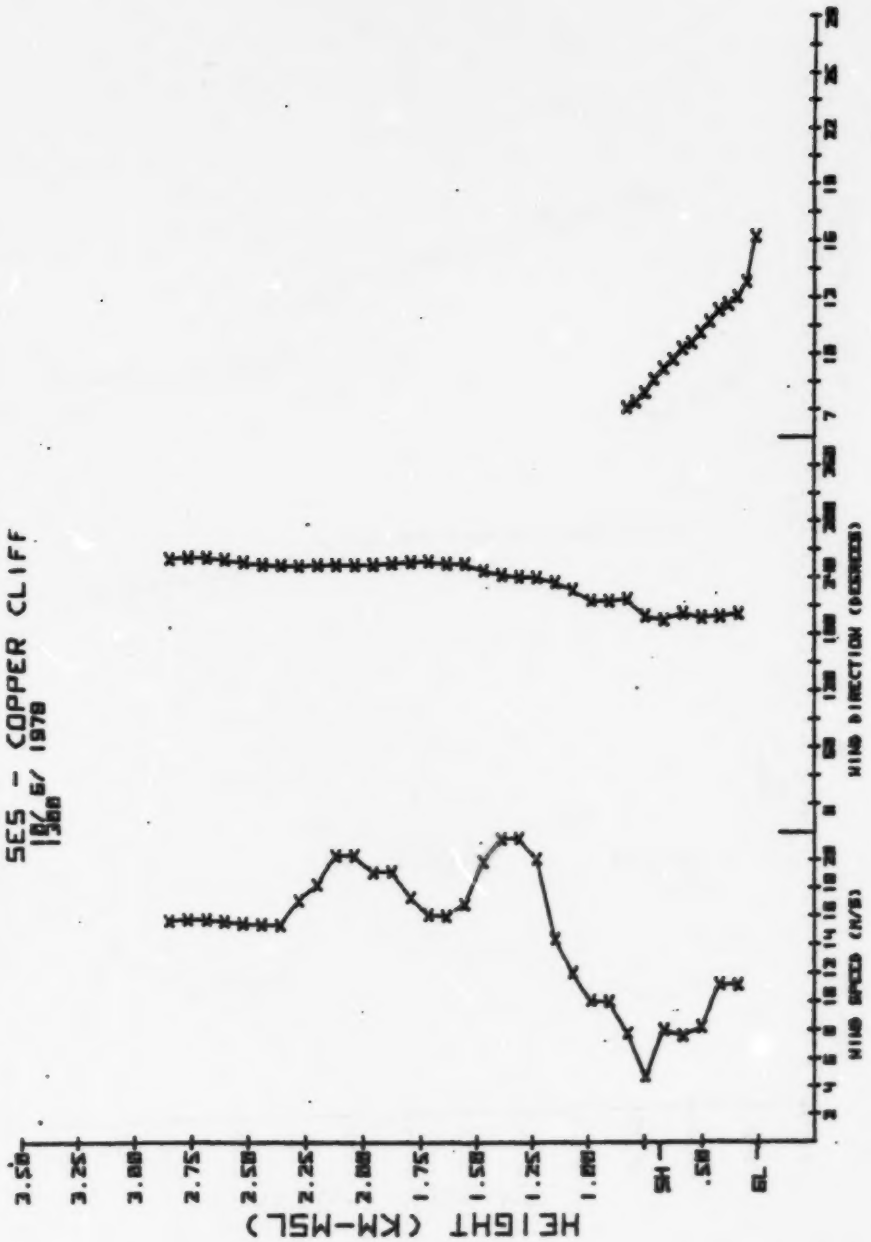

SES - COPPER CLIFF
1588' 1978
DALR
HEIGHT (KM-MSL)
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
TEMP. (DEGREES CELCIUS)

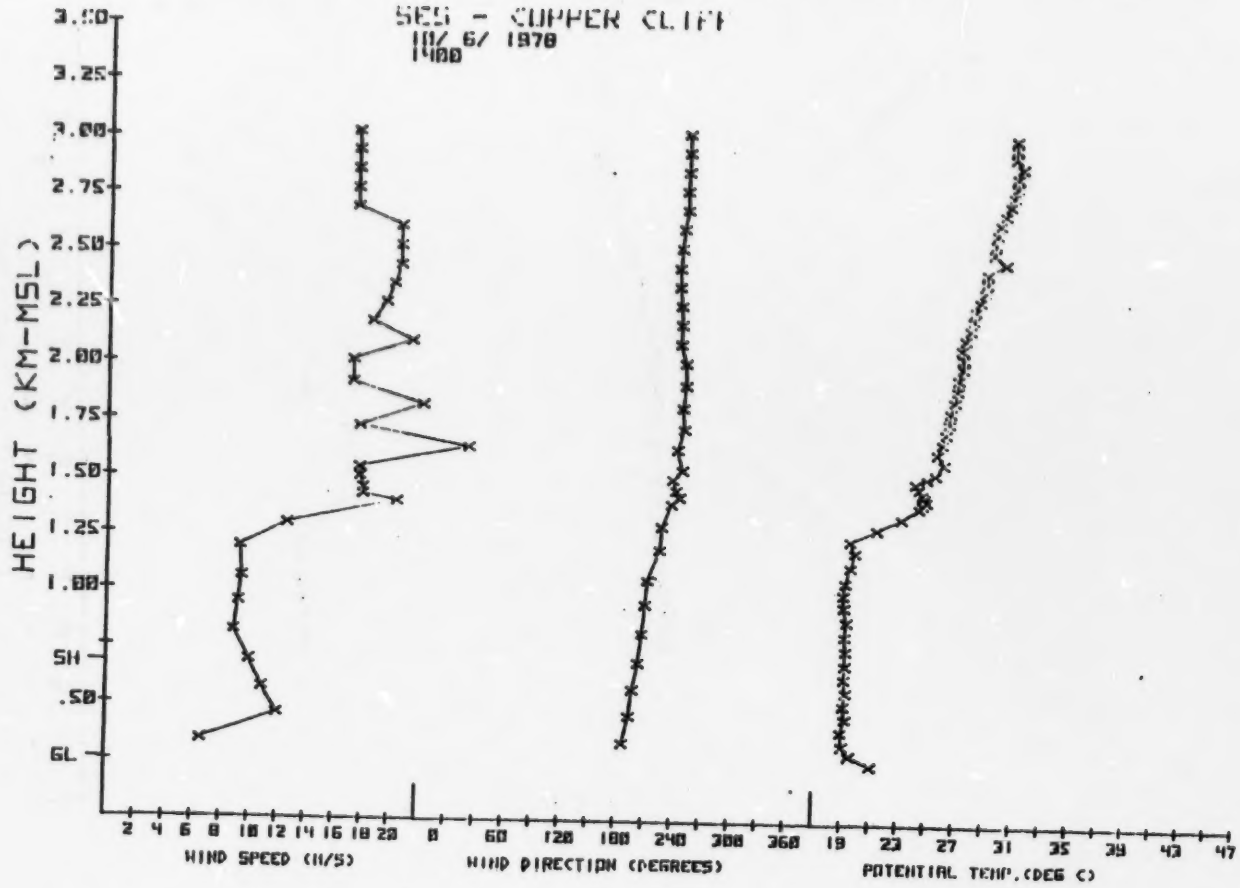

SES - COPPER CLIFF
1600 6/ 1978
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.5
EH
SL
WIND SPEED (KNOTS)
WIND DIRECTION (DEGREES)
TEMP. (DEGREES CELCIUS)
DALR

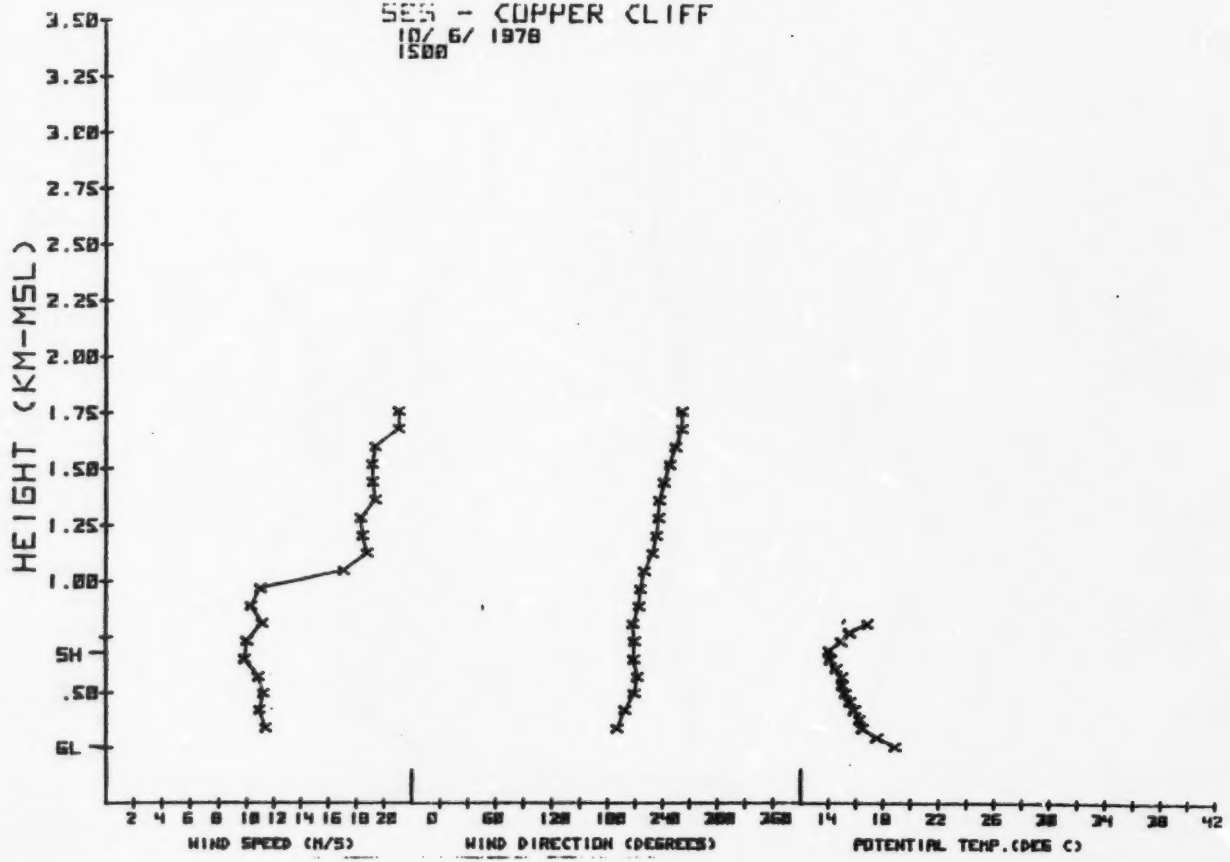

SES - COPPER CLIFF
1978
DALR
HEIGHT (KM-MSL)

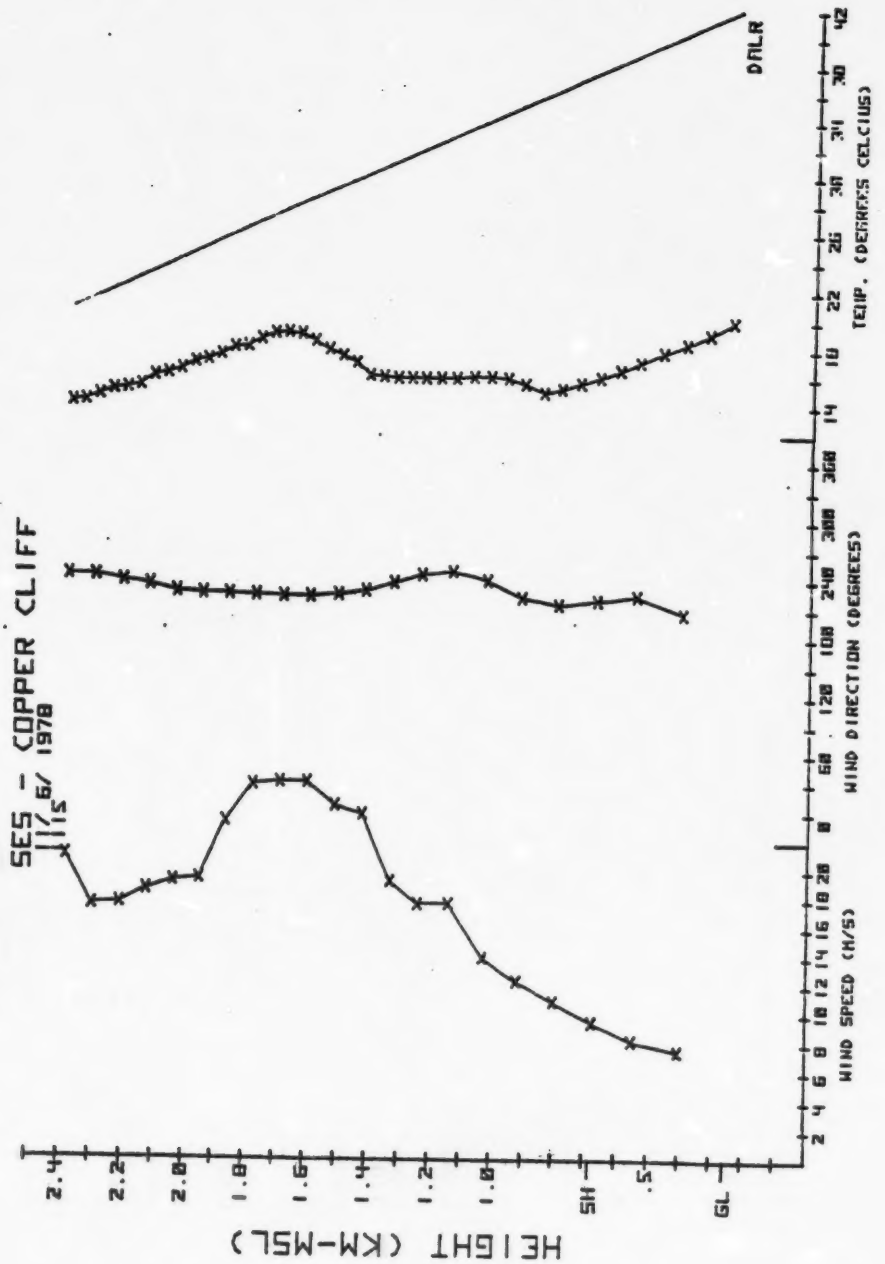

SES - COPPER CLIFF
DALR
HEIGHT (KM-MSL)
TEMP. (DEGREES CELCIUS)
WIND DIRECTION (DEGREES)
WIND SPEED (M/S)

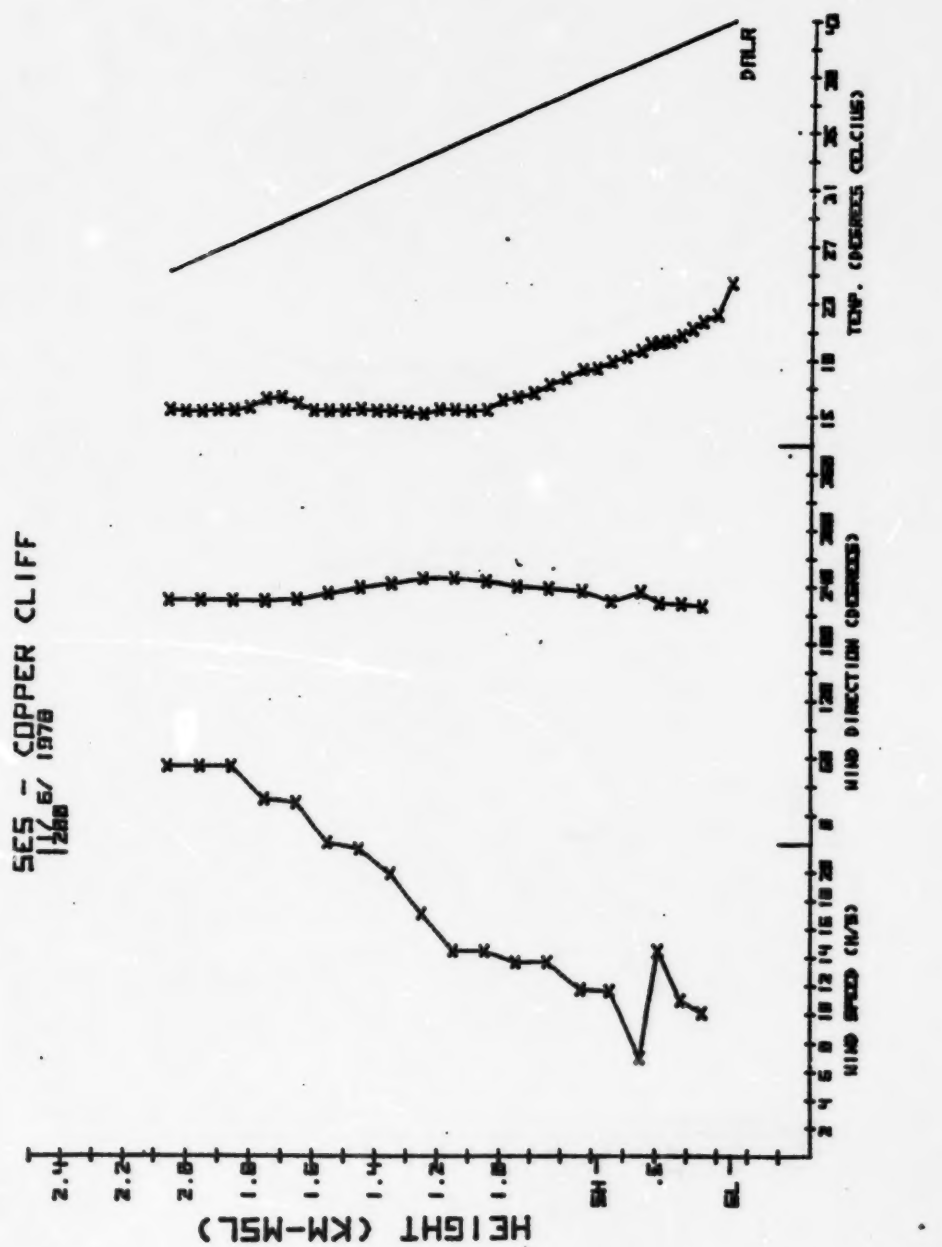

SES - COPPER CLIFF
1200 6/ 1978
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
SH
SL
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
TEMP. (DEGREES CELCIUS)

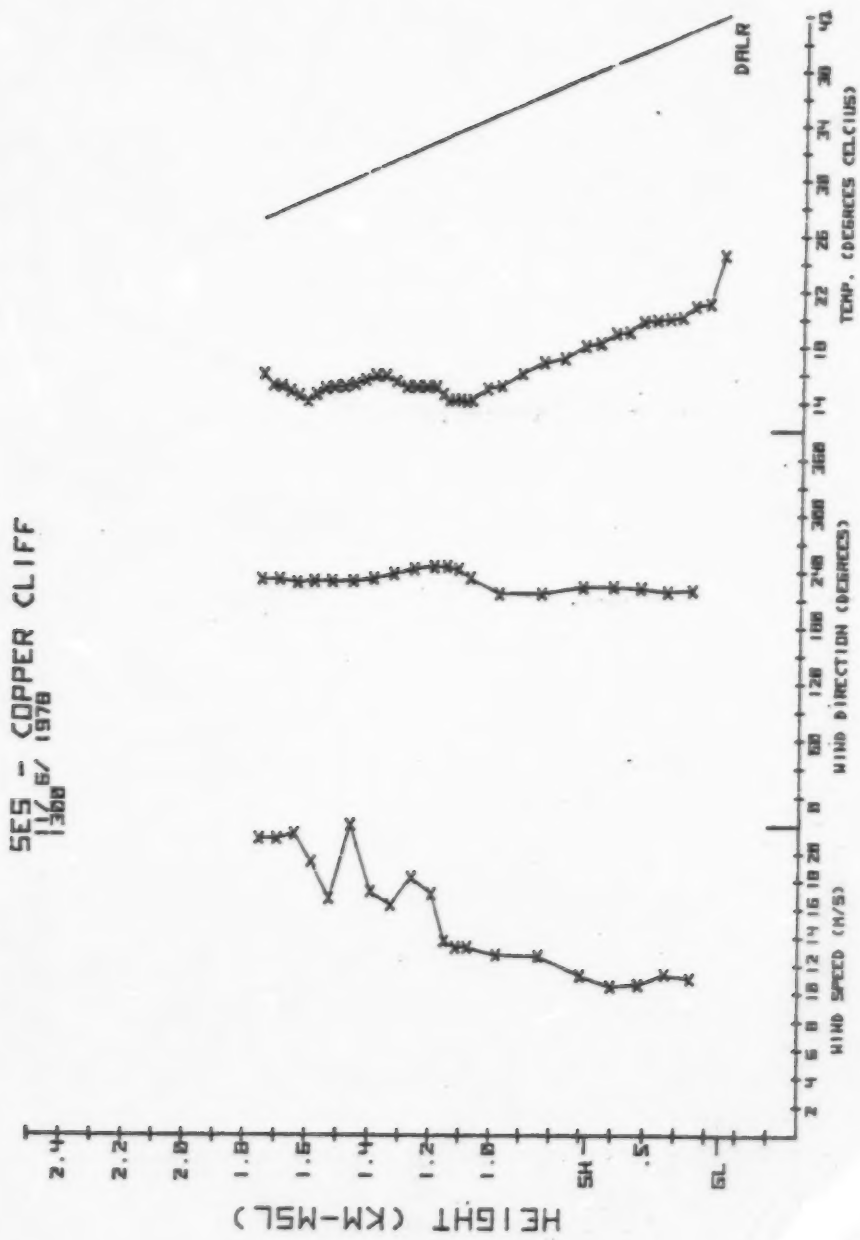

SES - COPPER CLIFF
1978
HEIGHT (KM-MSL)
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)

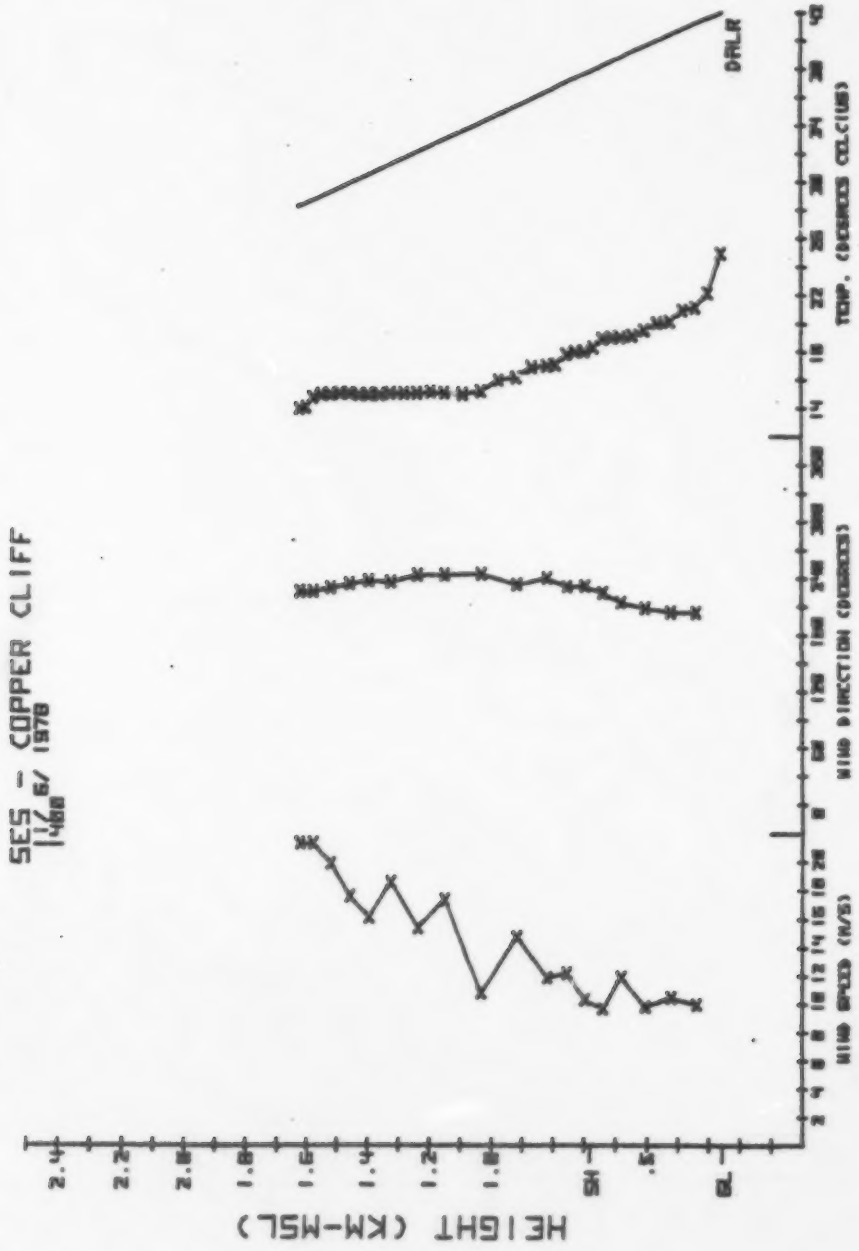

SES - COPPER CLIFF
10/ 6/ 1978
1100
HEIGHT (KM-MSL)
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
SH
.50
GL
2 4 6 8 10 12 14 16 18 20
WIND SPEED (M/S)
0 60 120 180 240 300 360
WIND DIRECTION (DEGREES)
19 23 27 31 35 39 43 47
POTENTIAL TEMP. (DEG C)

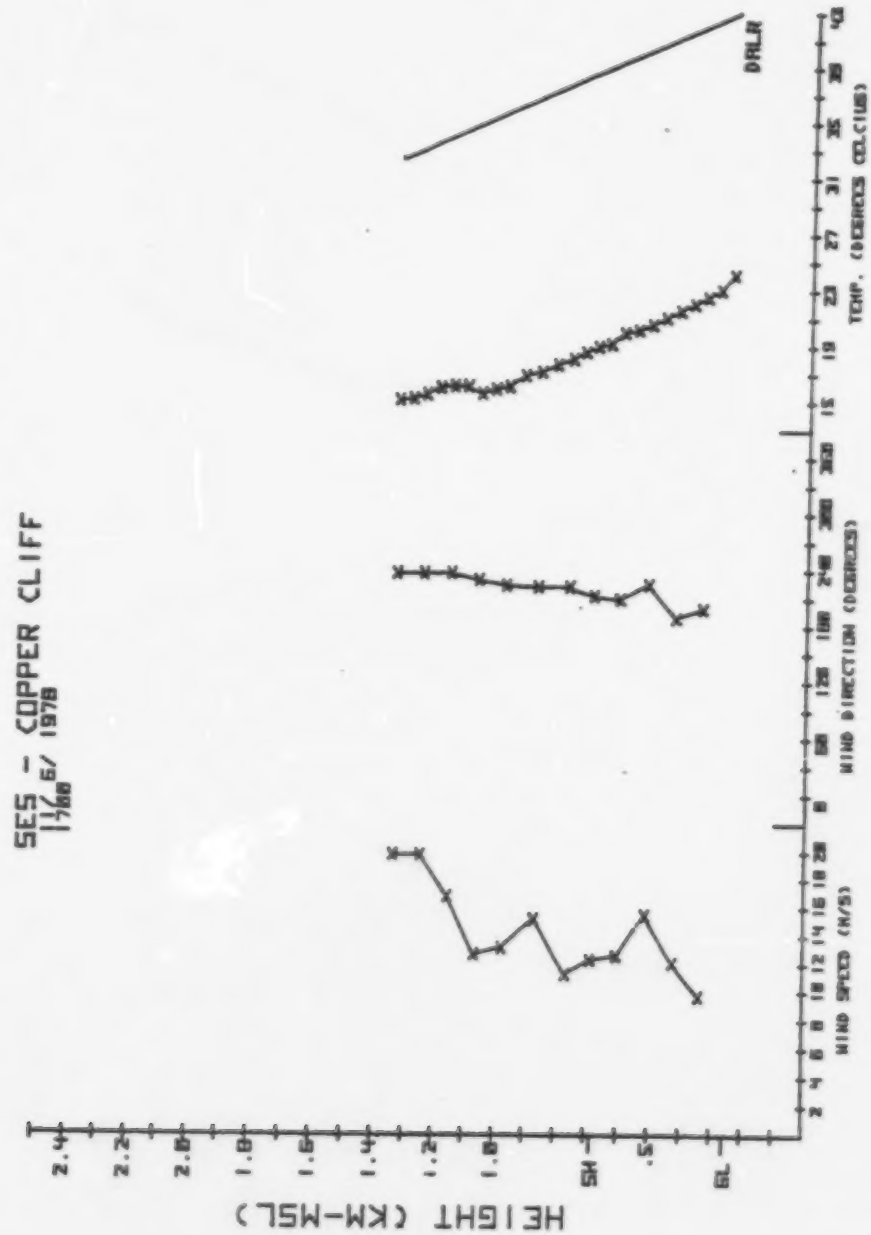

SES - COPPER CLIFF
10/ 6/ 1978
1500
HEIGHT (KM-MSL)
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
SH
.50
GL
2 4 6 8 10 12 14 16 18 20
WIND SPEED (M/S)
0 60 120 180 240 300 360
WIND DIRECTION (DEGREES)
14 18 22 26 30 34 38 42
POTENTIAL TEMP.(DEG C)

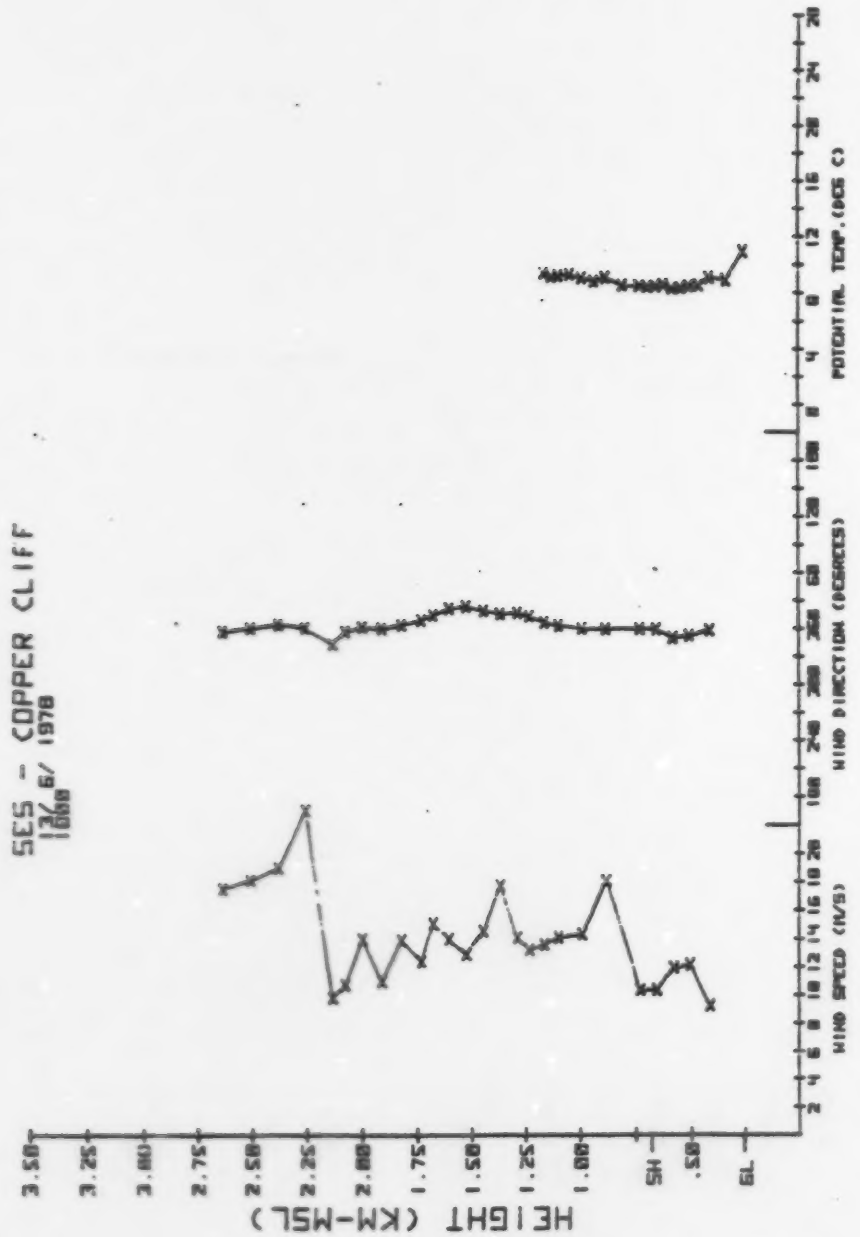

SES - COPPER CLIFF
11/5/ 1978
DALR
HEIGHT (KM-MSL)
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
TEMP. (DEGREES CELCIUS)
GL
HS

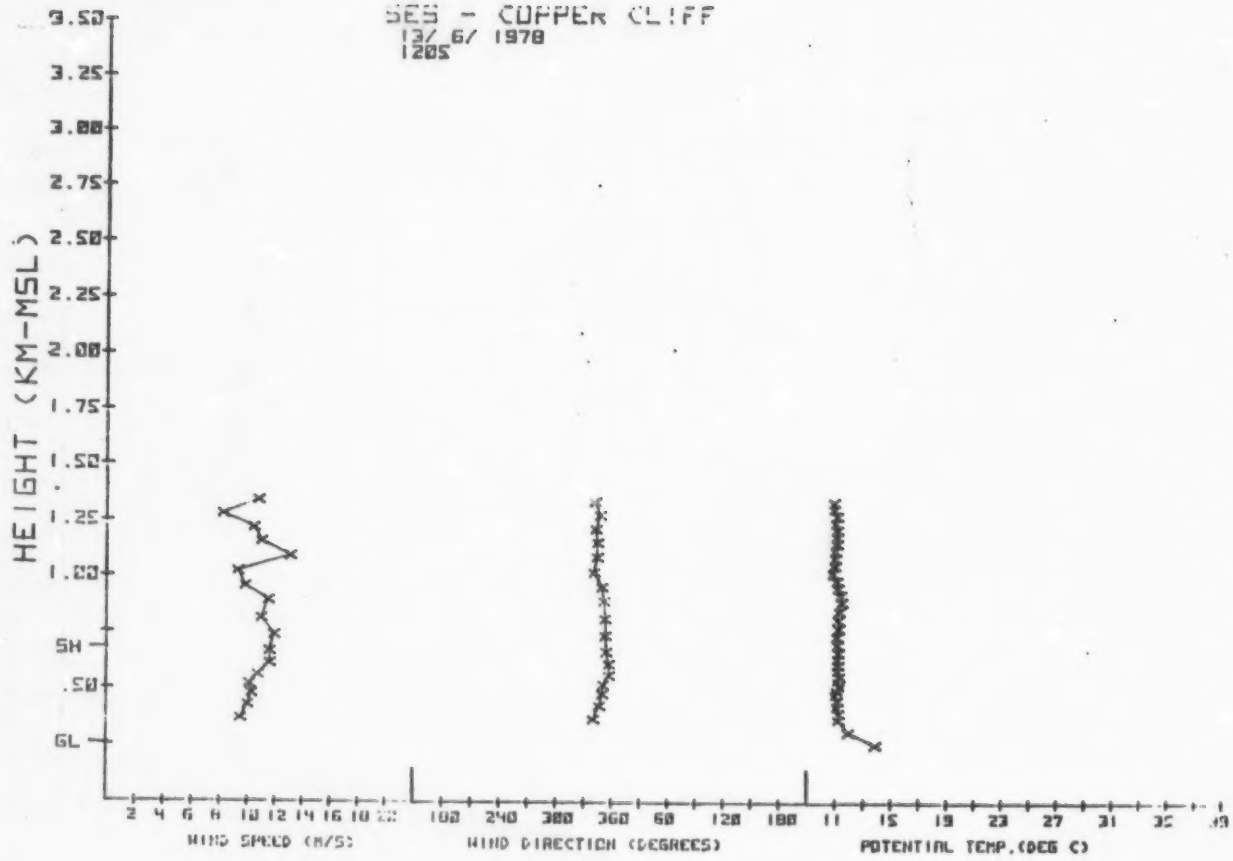

SES - COPPER CLIFF
12/06/ 1978
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
SL
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
TEMP. (DEGREES CELCIUS)
DALR

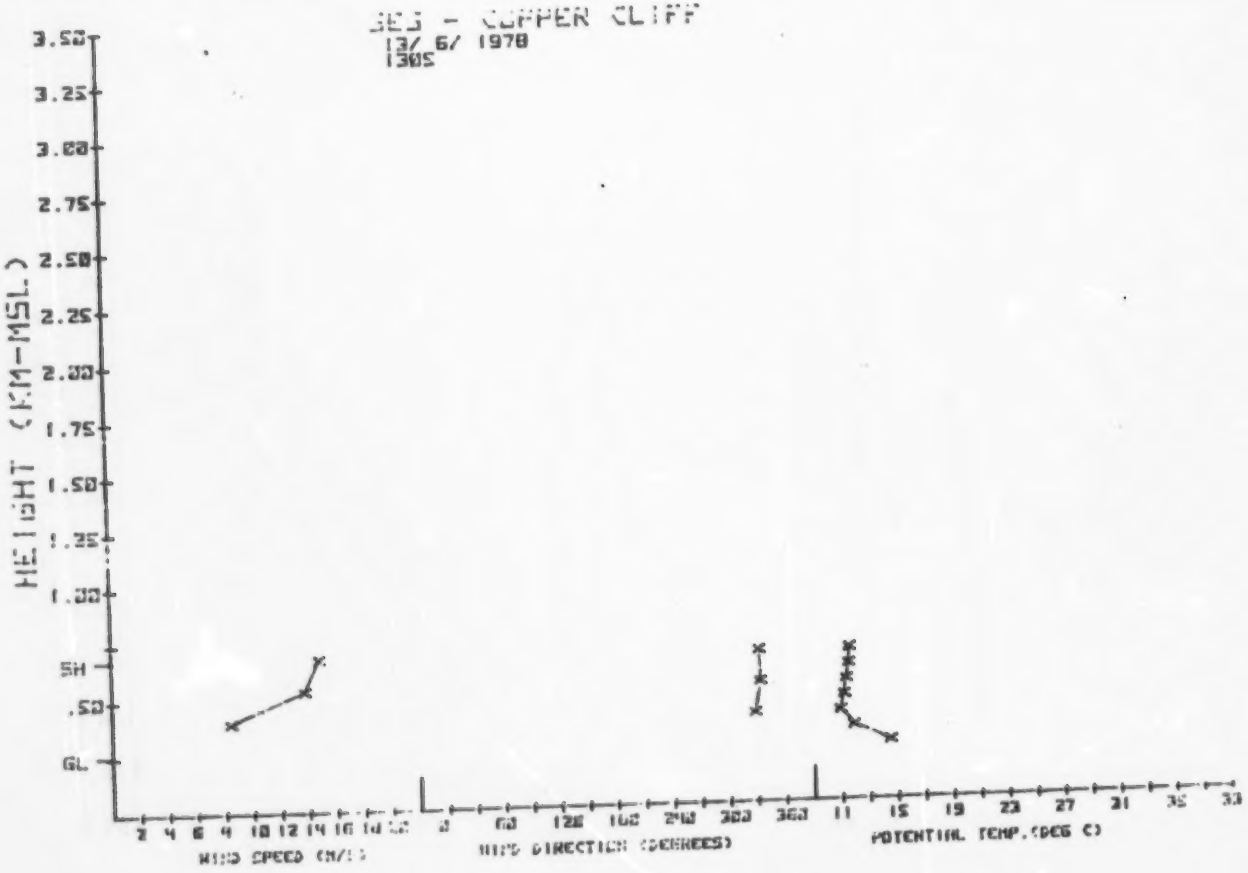

SES - COPPER CLIFF
1360 6/ 1978
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.5
SH
SL
WIND SPEED (M/S)
2 4 6 8 10 12 14 16 18 20
WIND DIRECTION (DEGREES)
0 60 120 180 240 300 360
TEMP. (DEGREES CELCIUS)
10 14 18 22 26 30 34 38 42
DALR

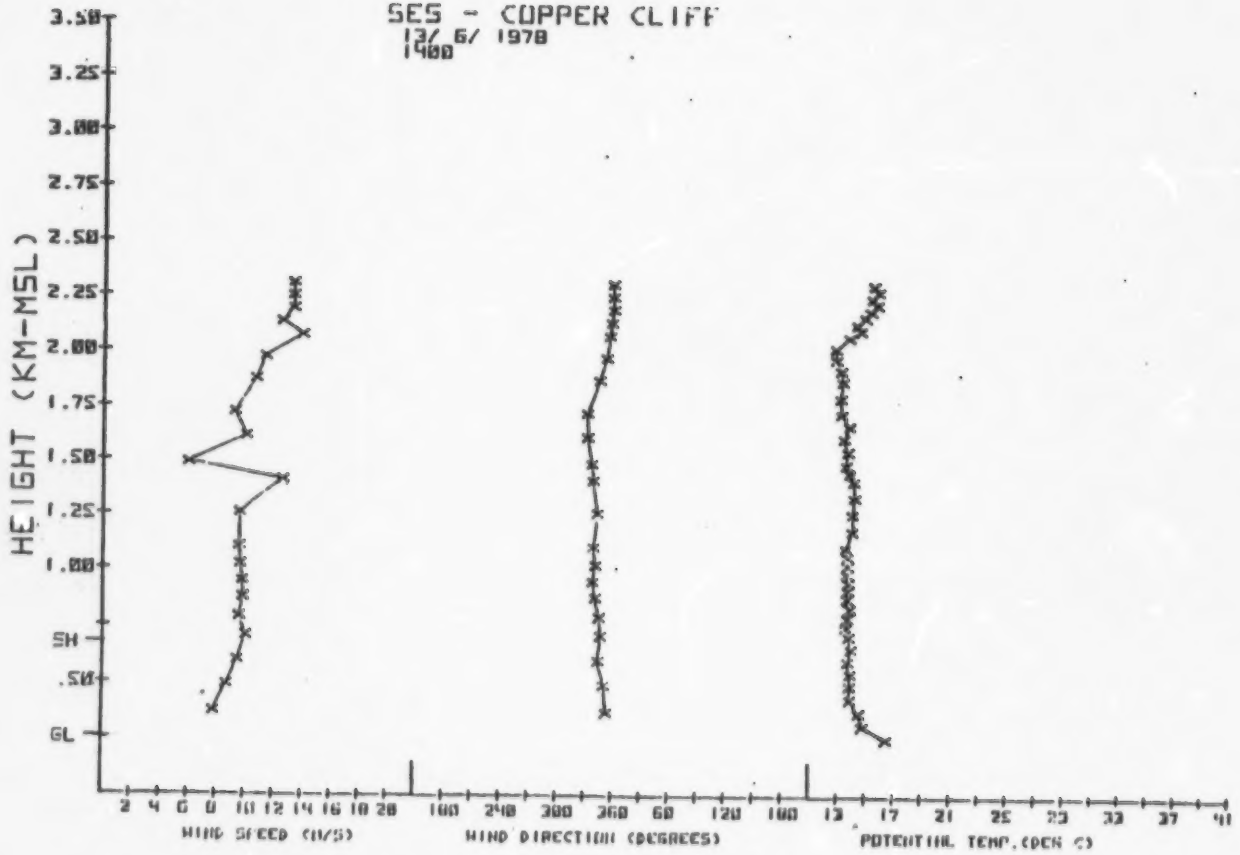

SES - COPPER CLIFF
17 6/ 1978
1468
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
SH
GL
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
TEMP. (DEGREES CELCIUS)
DALR

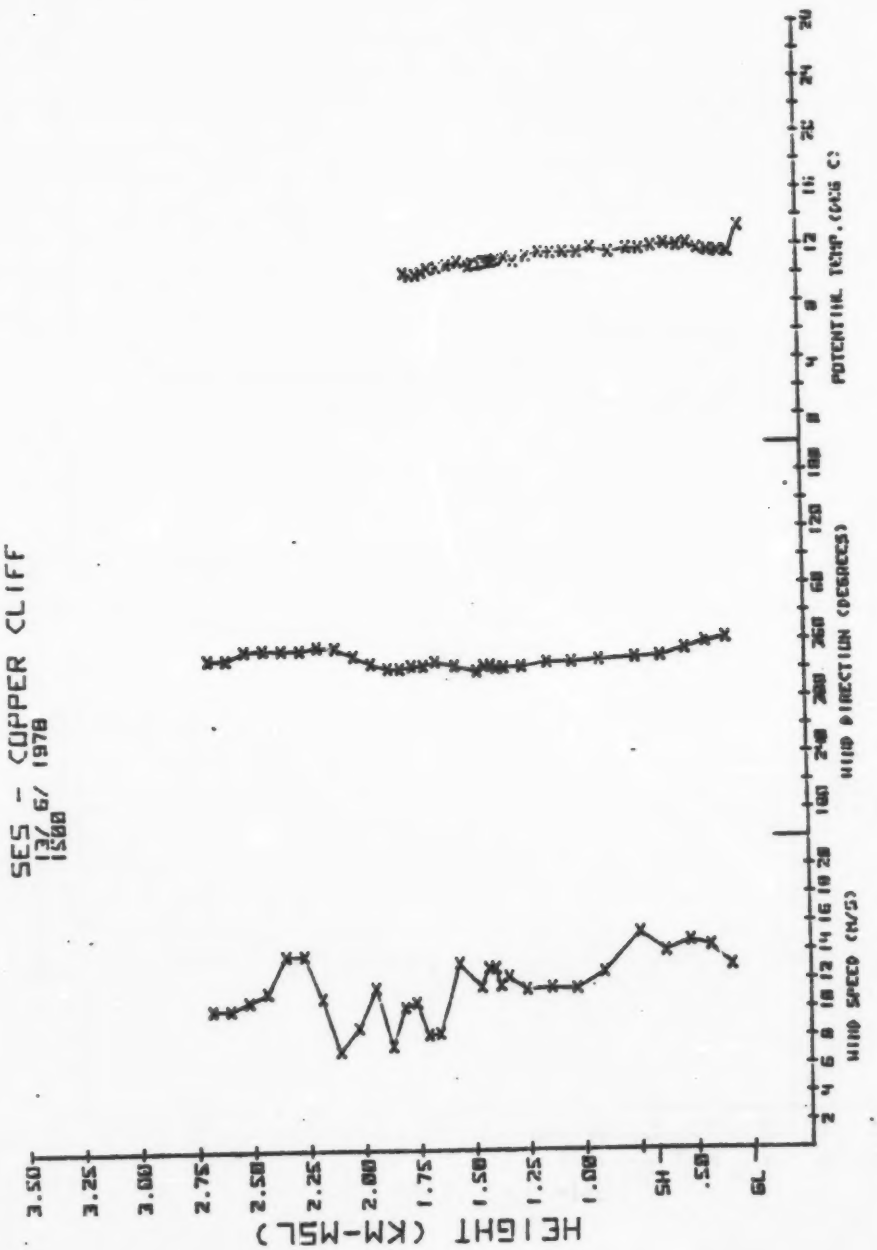

SES - COPPER CLIFF
11/06/ 1978
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.5
HS
GL
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
TEMP. (DEGREES CELCIUS)
DALR

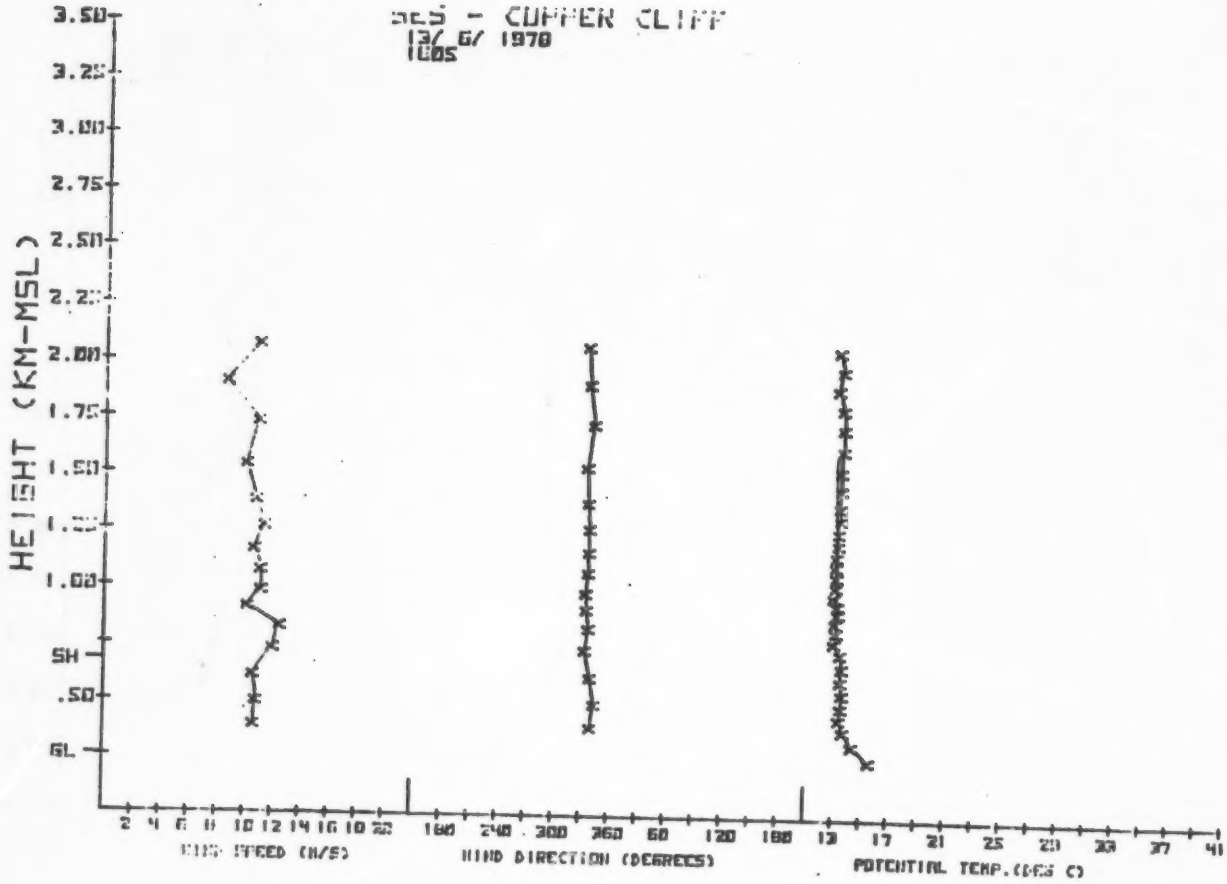

SES - COPPER CLIFF
13/ 6/ 1978
1000
HEIGHT (KM-MSL)
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
.75
.50
.25
HS
TS
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP.(DEG C)

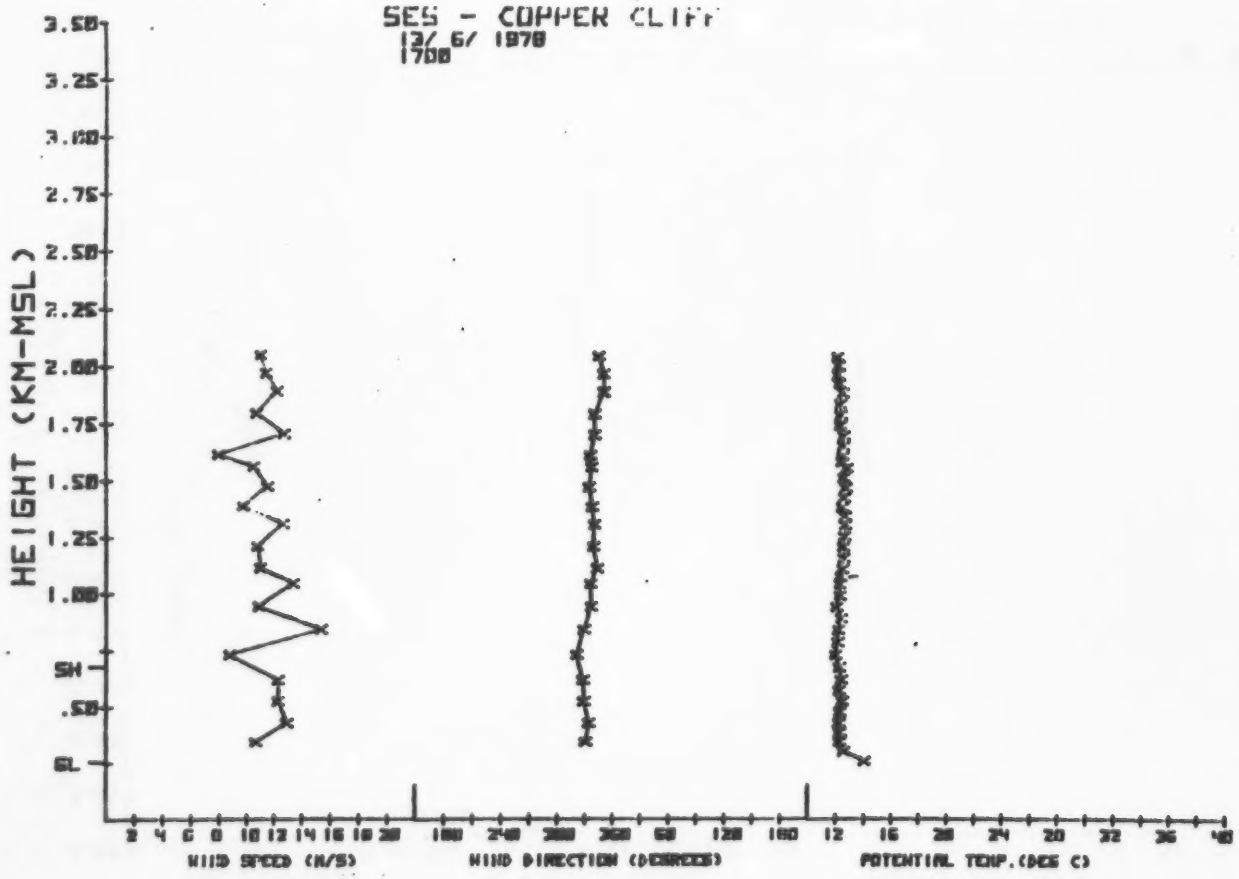

SES - COPPER CLIFF
13/ 6/ 1978
1205
HEIGHT (KM-MSL)
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
SH
.50
GL
2 4 6 8 10 12 14 16 18 20
WIND SPEED (M/S)
100 240 300 360 60 120 180
WIND DIRECTION (DEGREES)
11 15 19 23 27 31 35
POTENTIAL TEMP.(DEG C)

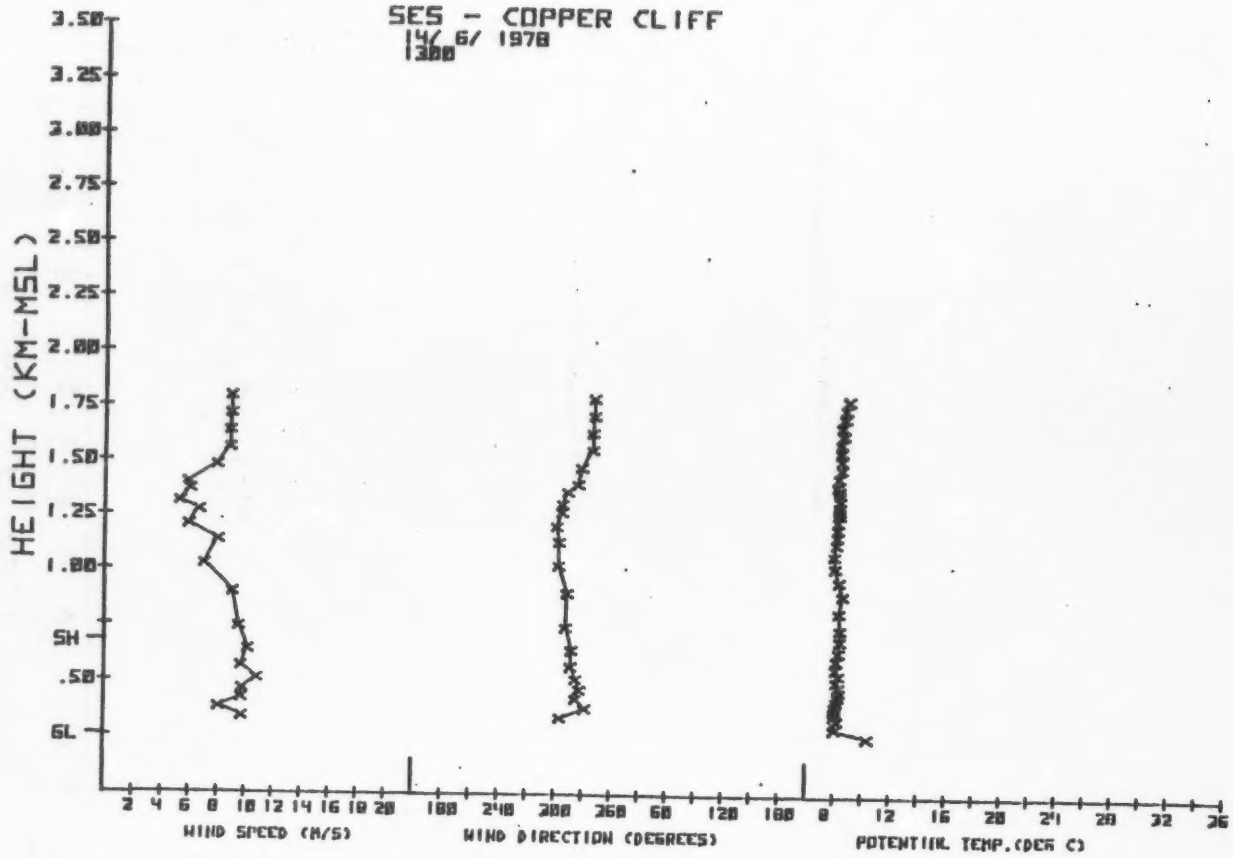

SES - COPPER CLIFF
13/ 6/ 1978
1305
HEIGHT (KM-MSL)
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
SH
.50
GL
2 4 6 8 10 12 14 16 18 20
WIND SPEED (M/S)
0 60 120 180 240 300 360
WIND DIRECTION (DEGREES)
11 15 19 23 27 31 35 39
POTENTIAL TEMP.(DEG C)

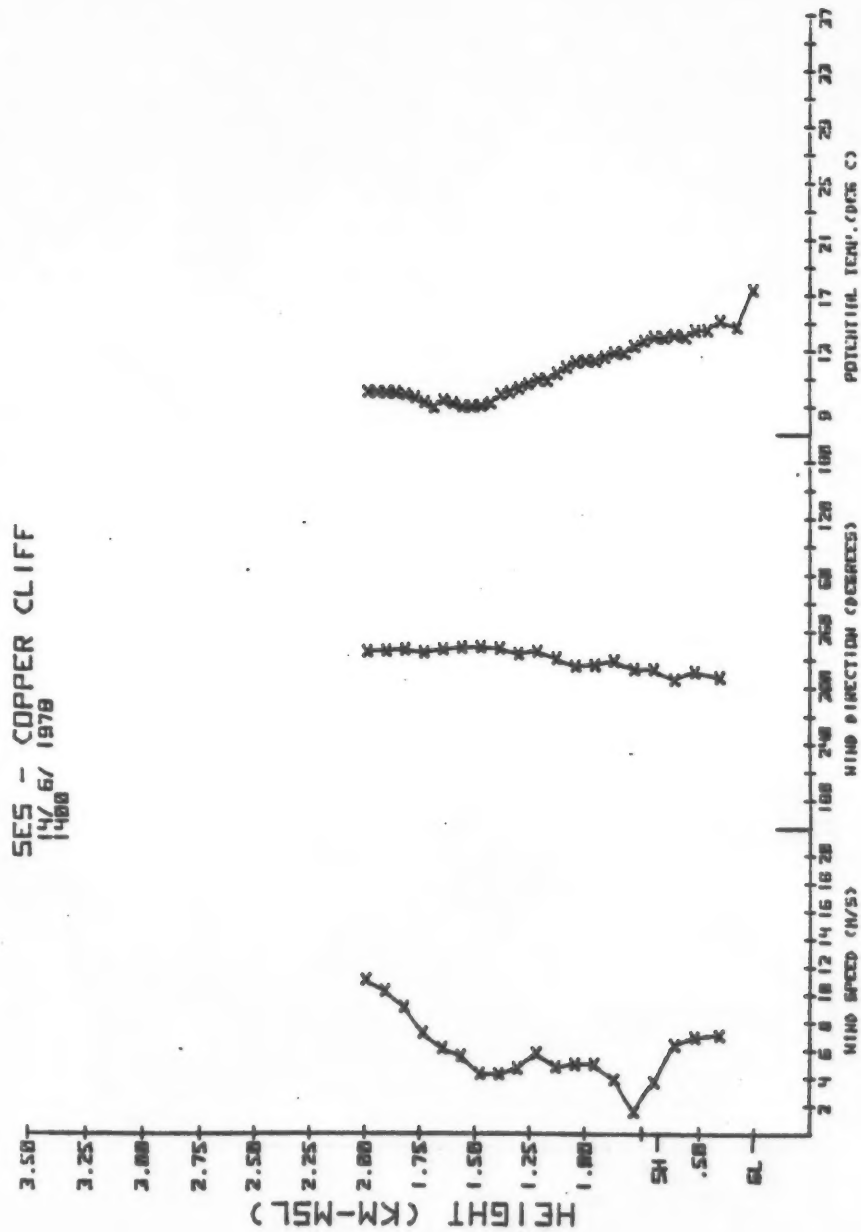

SES - COPPER CLIFF
13/ 6/ 1978
1400
HEIGHT (KM-MSL)
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
SH
.50
GL
2 4 6 8 10 12 14 16 18 20
WIND SPEED (M/S)
100 240 300 360 60 120 180
WIND DIRECTION (DEGREES)
13 17 21 25 29 33 37 41
POTENTIAL TEMP. (DEG C)

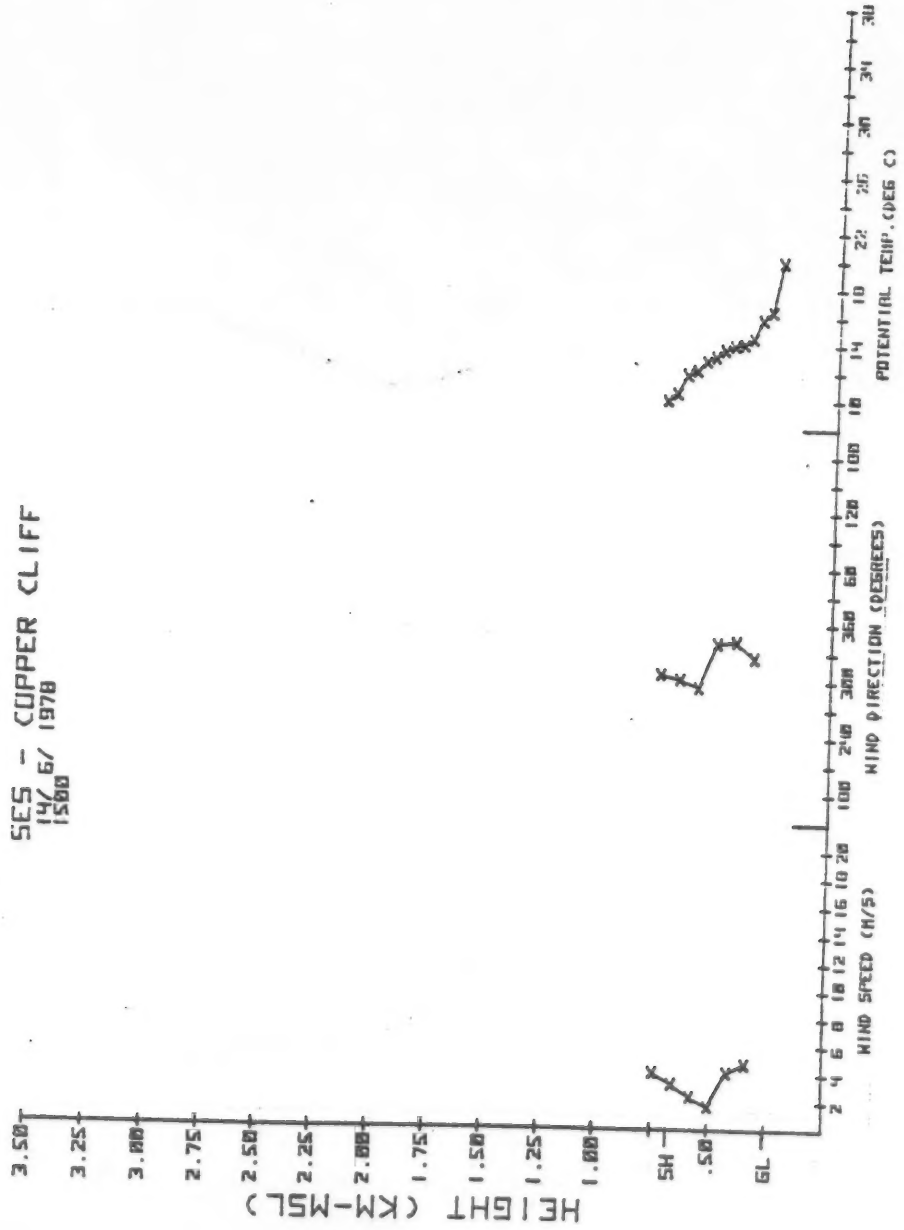

SES - COPPER CLIFF
13/ 6/ 1978
1500
HEIGHT (KM-MSL)
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
.75
.50
HS
ML
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG C)

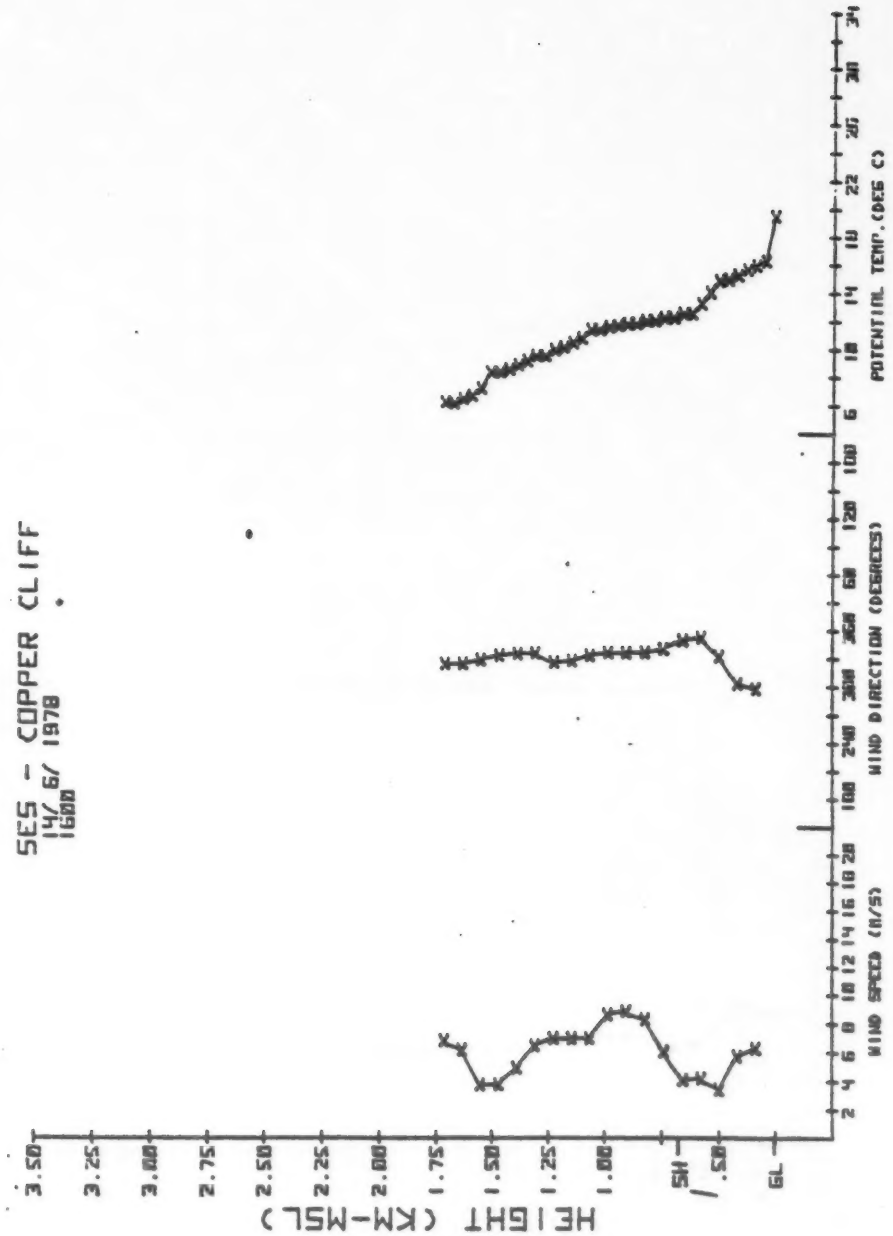

DES - CUPPER CLIFF
1005
1970
HEIGHT (KM-MSL)
3.50
3.25
3.00
2.75
2.50
2.00
1.75
1.50
1.00
SH
.50
GL
2 4 6 8 10 12 14 16 18 20
180 240 300 360 60 120 180
13 17 21 25 29 33 37 41
WIND DIRECTION (DEGREES)
POTENTIAL TEMP.(DEG C)

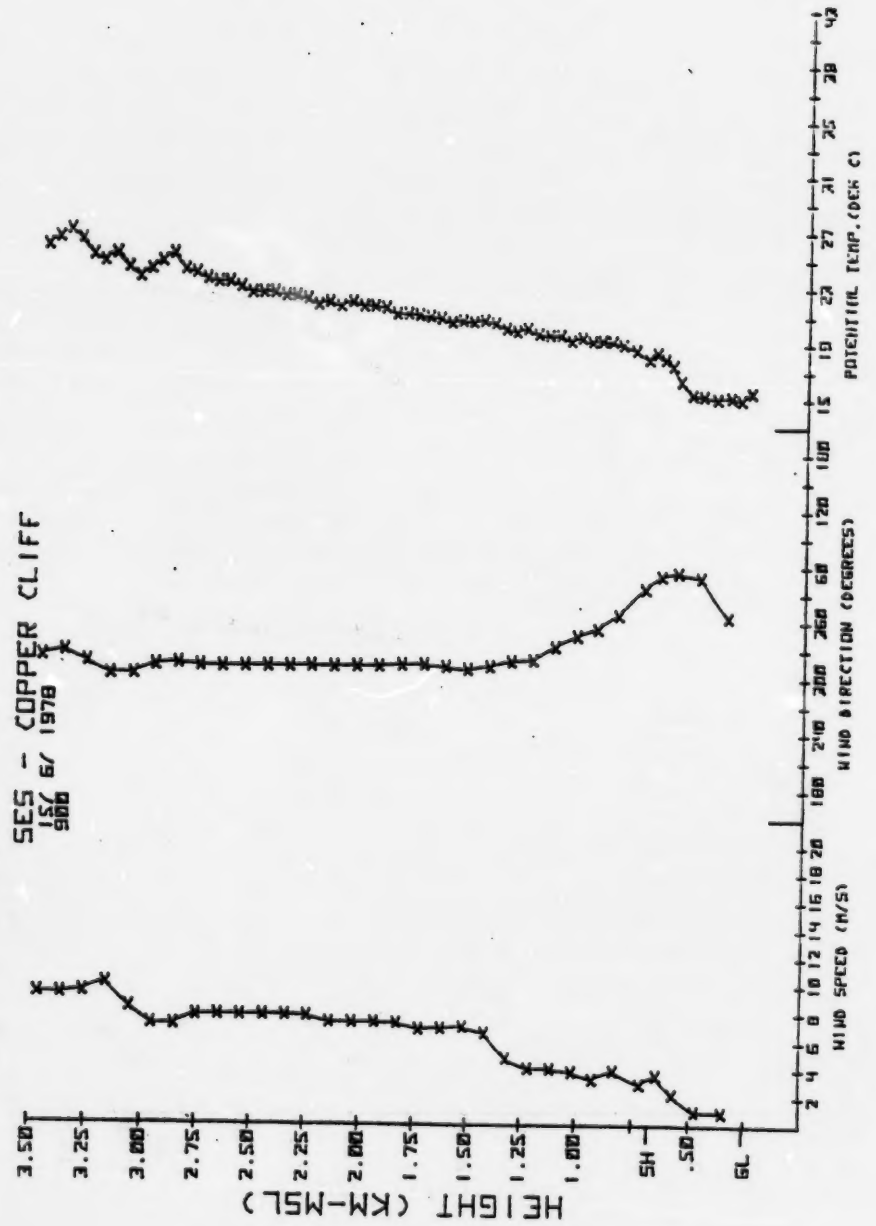

SES - COPPER CLIFF
13/ 6/ 1978
1700
HEIGHT (KM-MSL)
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
SH
.50
GL
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG C)

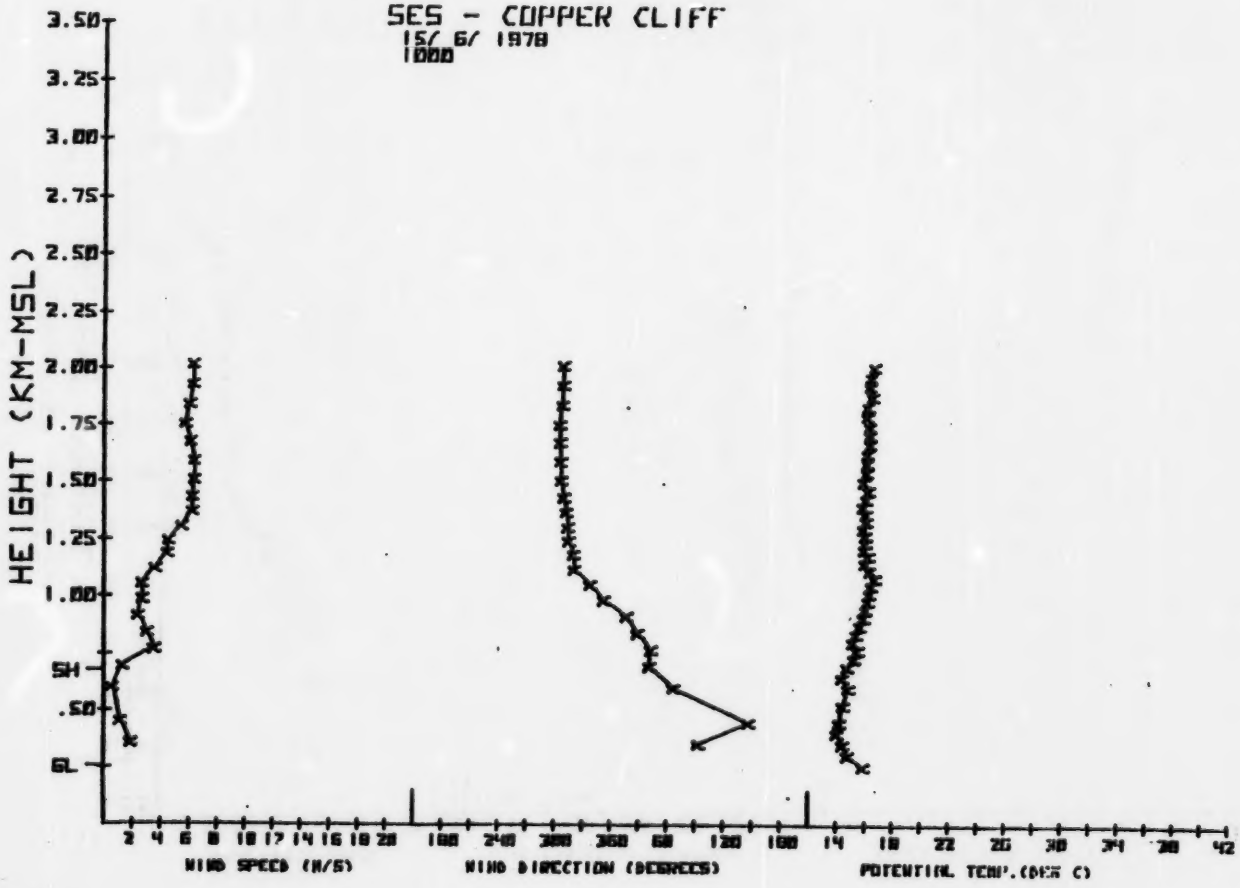

SES - COPPER CLIFF
14/ 6/ 1978
1300
HEIGHT (KM-MSL)
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
SH
.50
GL
2 4 6 8 10 12 14 16 18 20
WIND SPEED (M/S)
180 240 300 360 60 120 180
WIND DIRECTION (DEGREES)
0 12 16 20 24 28 32 36
POTENTIAL TEMP. (DEG C)

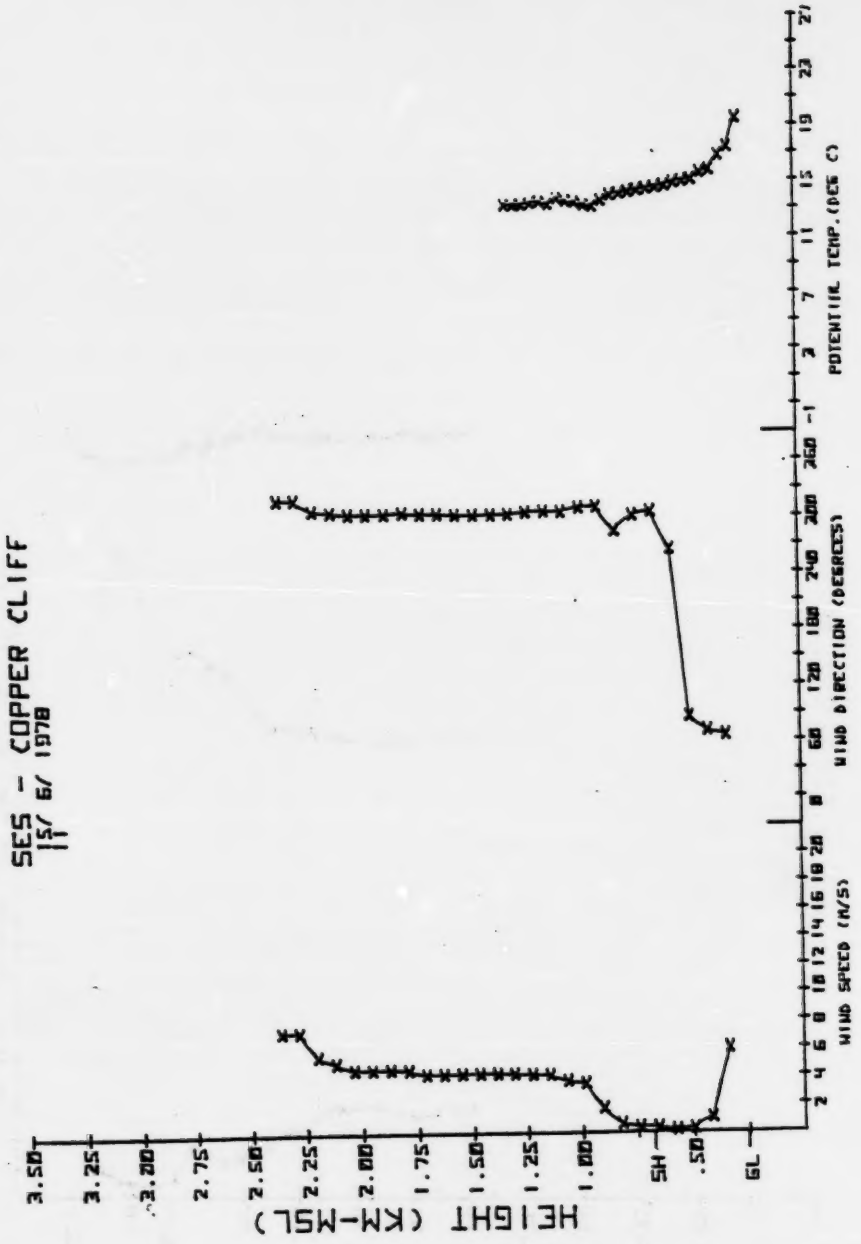

SES - COPPER CLIFF
14/ 6/ 1978
1400
HEIGHT (KM-MSL)
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
.75
.50
SH
SL
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG C)

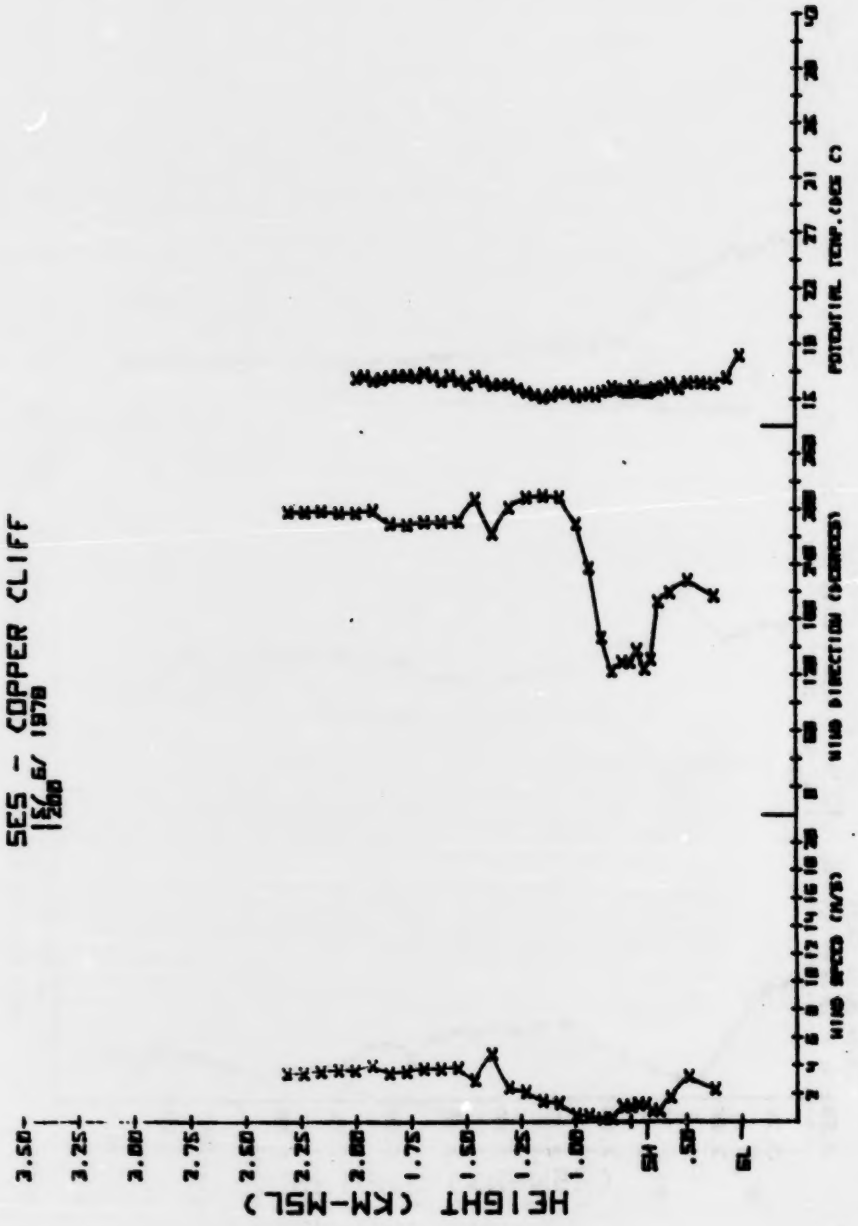

SES - COPPER CLIFF
14/ 6/ 1978
1500
HEIGHT (KM-MSL)
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
SH
.50
GL
2 4 6 8 10 12 14 16 18 20
WIND SPEED (M/S)
60 120 180 240 300 360
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG C)

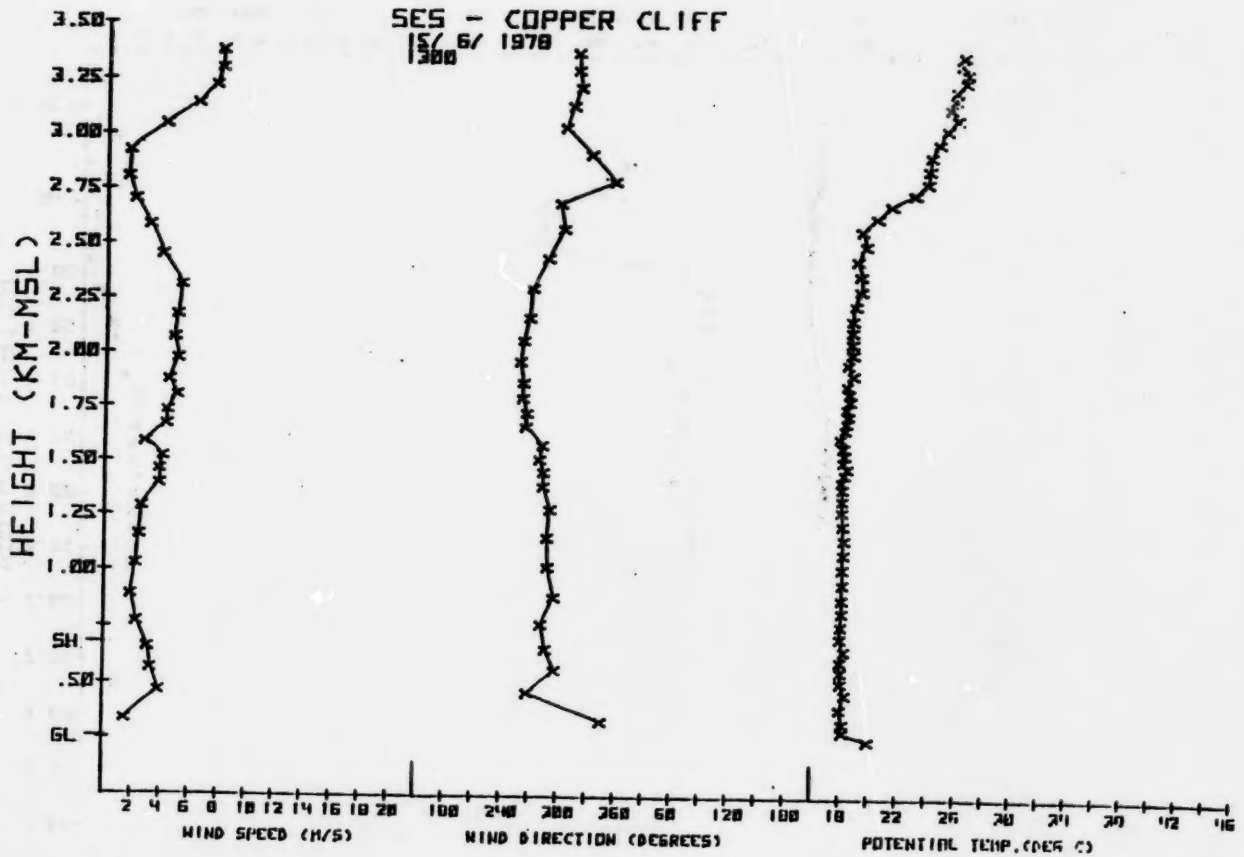

SES - COPPER CLIFF
14/ 6/ 1978
1600
HEIGHT (KM-MSL)
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
SH
.50
GL
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG C)

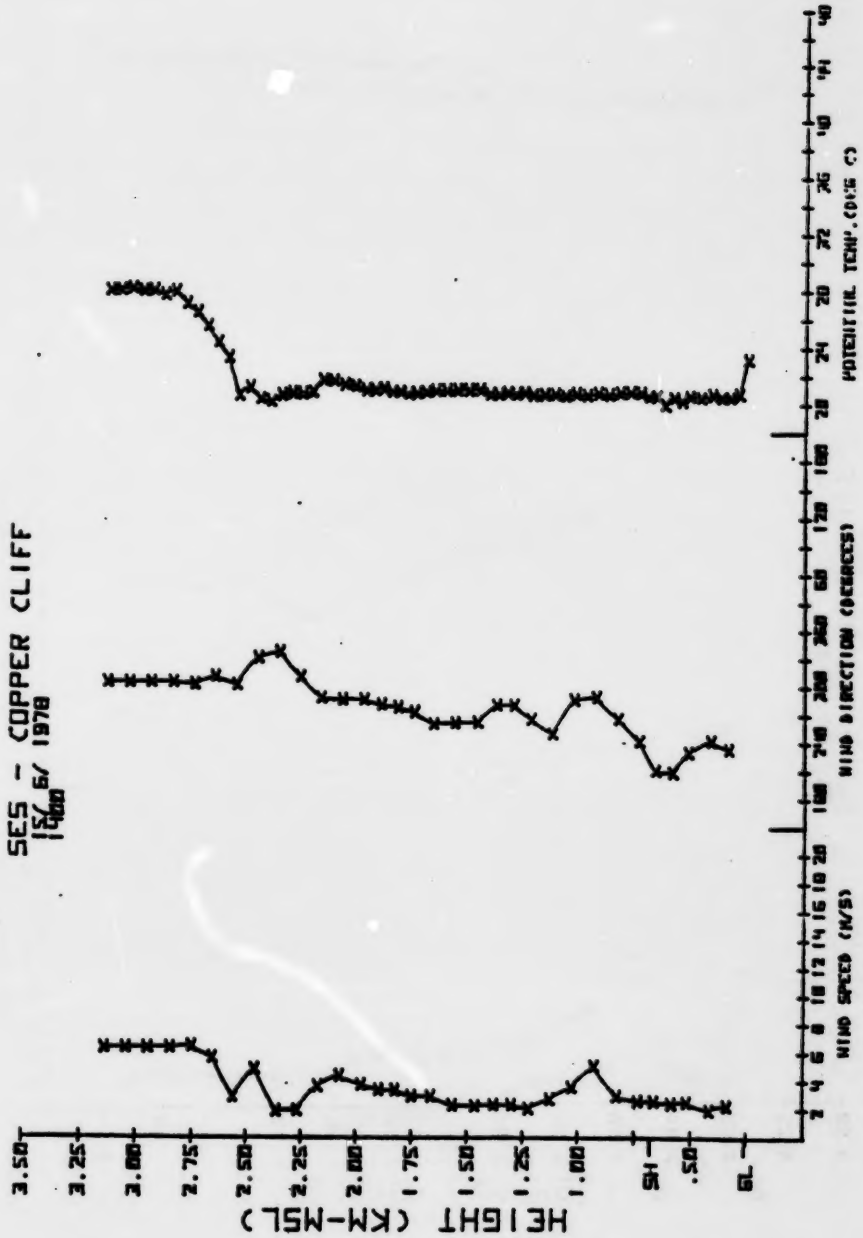

SES - COPPER CLIFF
15/ 6/ 1978
900
HEIGHT (KM-MSL)
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
SH
.50
GL
WIND SPEED (M/S)
2 4 6 8 10 12 14 16 18 20
WIND DIRECTION (DEGREES)
180 210 240 270 300 330 360 30 60 90 120 150 180
POTENTIAL TEMP. (DEG C)
15 19 23 27 31 35 39 43

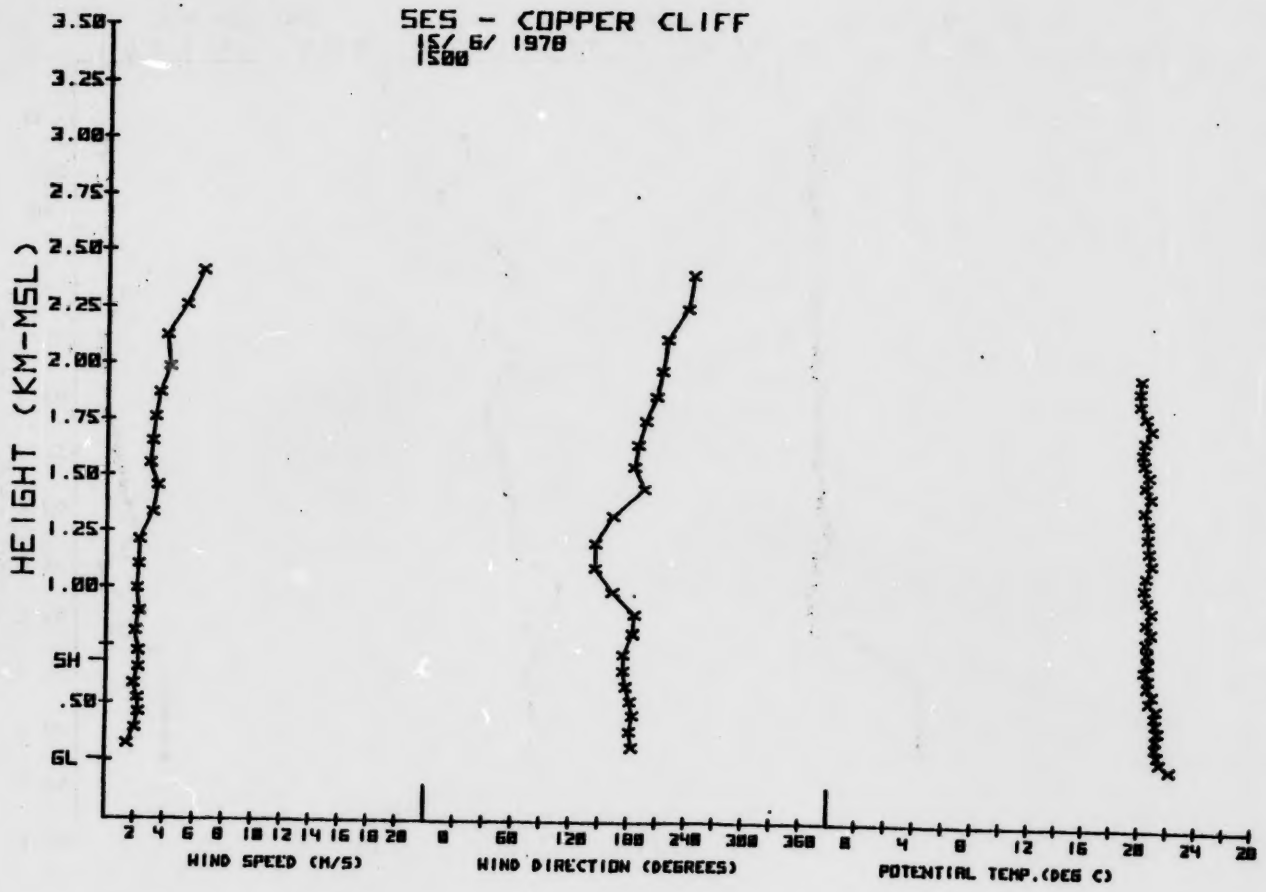

SES - COPPER CLIFF
15/ 6/ 1978
1000
HEIGHT (KM-MSL)
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
SH
.50
GL
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG C)

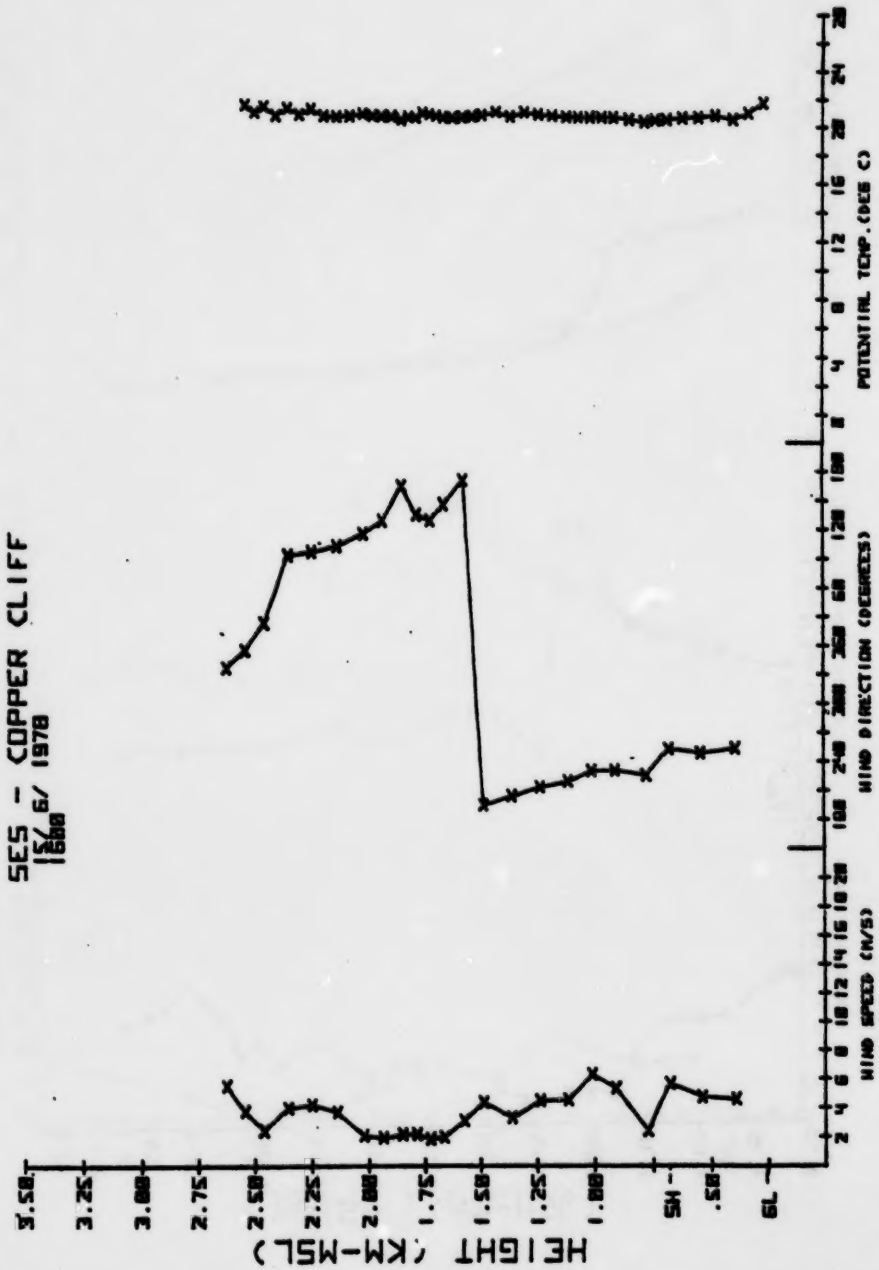

SES - COPPER CLIFF
15/ 6/ 1978
11
HEIGHT (KM-MSL)
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
SH
.50
SL
WIND SPEED (M/S)
2 4 6 8 10 12 14 16 18 20
WIND DIRECTION (DEGREES)
0 60 120 180 240 300 360
POTENTIAL TEMP.(DEG C)
-1 3 7 11 15 19 23 27

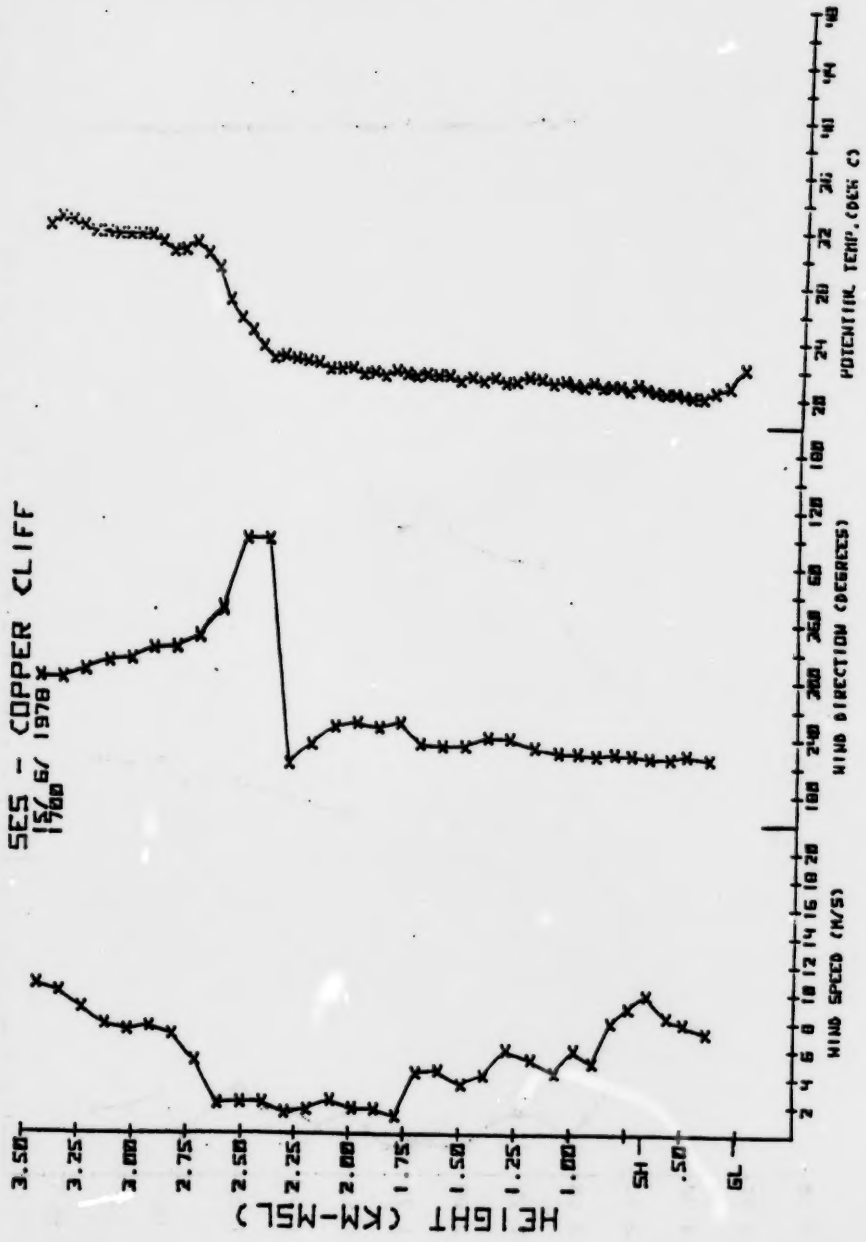

SES - COPPER CLIFF
15/1200 GMT 1978
HEIGHT (KM-MSL)
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
.50
SL
WIND SPEED (KTS)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG C)

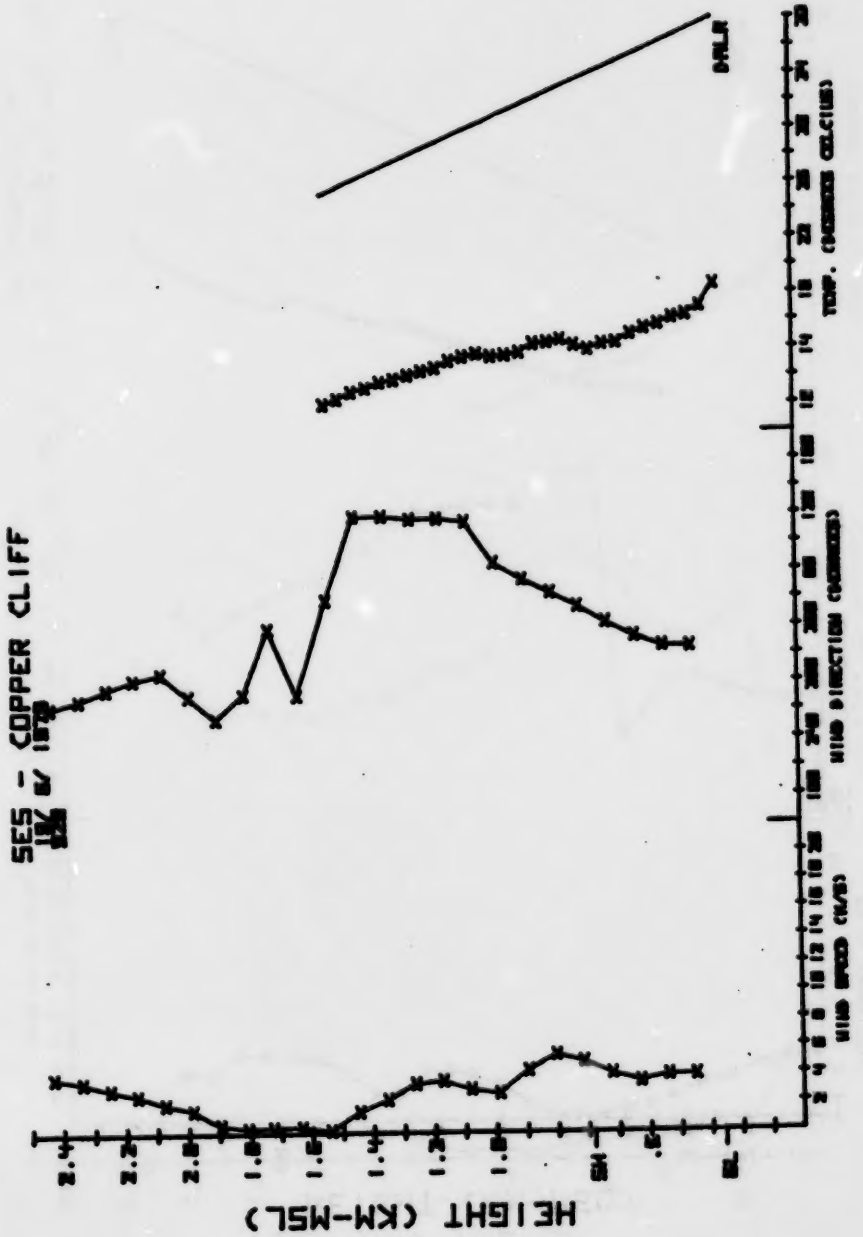

SES - COPPER CLIFF
15/ 6/ 1978
1300
HEIGHT (KM-MSL)
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
SH
.50
GL
2 4 6 8 10 12 14 16 18 20
WIND SPEED (M/S)
100 140 180 220 260 60 120 180
WIND DIRECTION (DEGREES)
18 22 26 30 34 38 42 46
POTENTIAL TEMP.(DEG C)

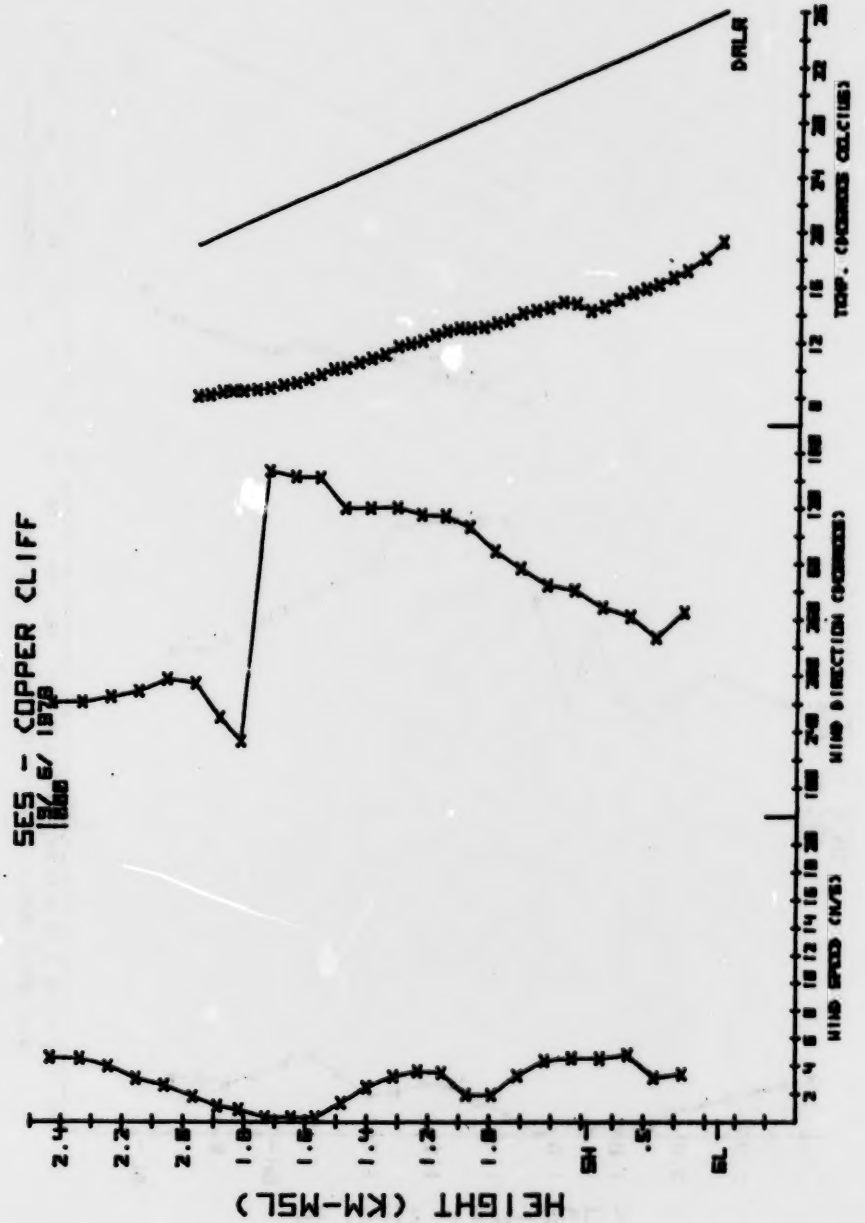

SES - COPPER CLIFF
15/ 6/ 1978
1400
HEIGHT (KM-MSL)
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
SH
.50
GL
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG C)

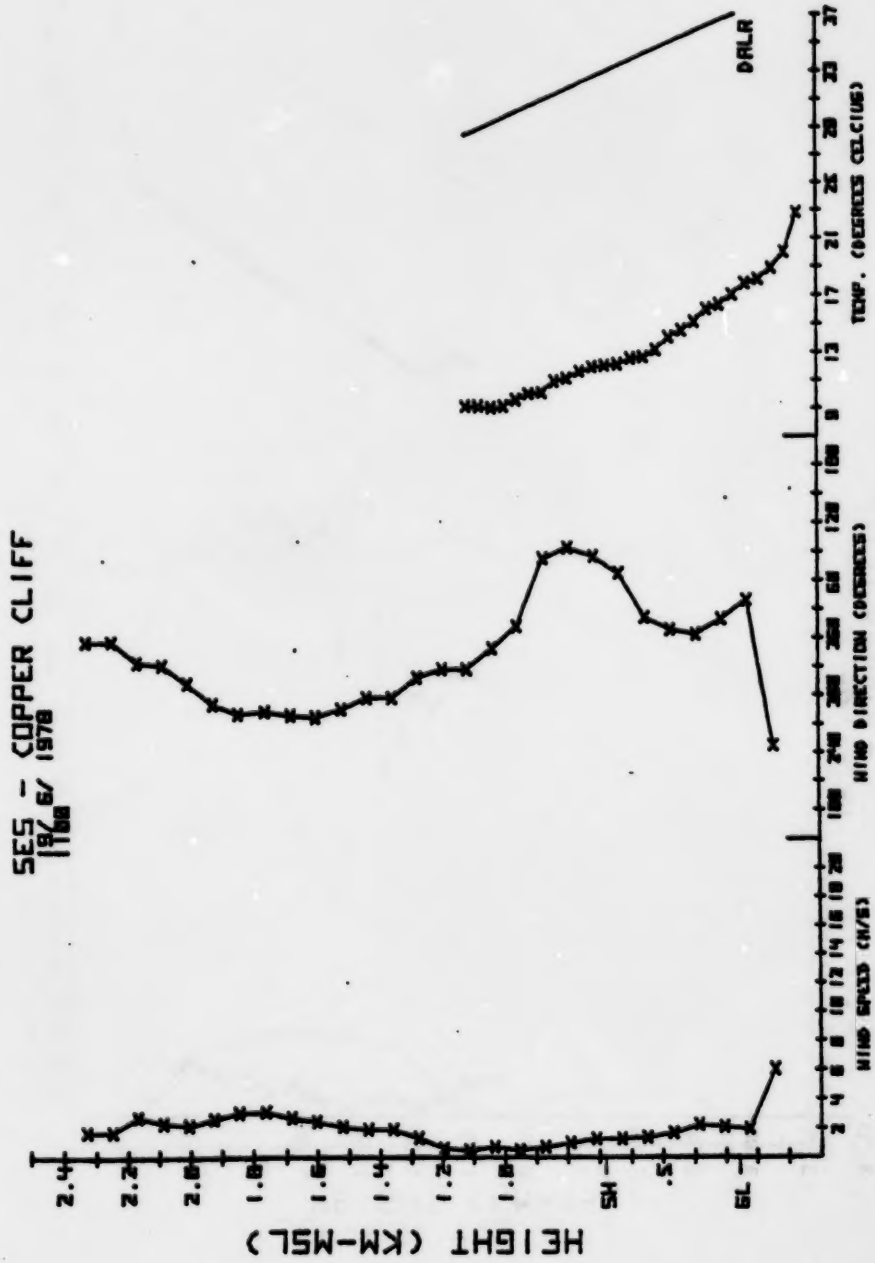

SES - COPPER CLIFF
15/ 6/ 1978
1500
HEIGHT (KM-MSL)
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
SH
.50
GL
2 4 6 8 10 12 14 16 18 20
WIND SPEED (M/S)
0 60 120 180 240 300 360
WIND DIRECTION (DEGREES)
0 4 8 12 16 20 24 28
POTENTIAL TEMP. (DEG C)

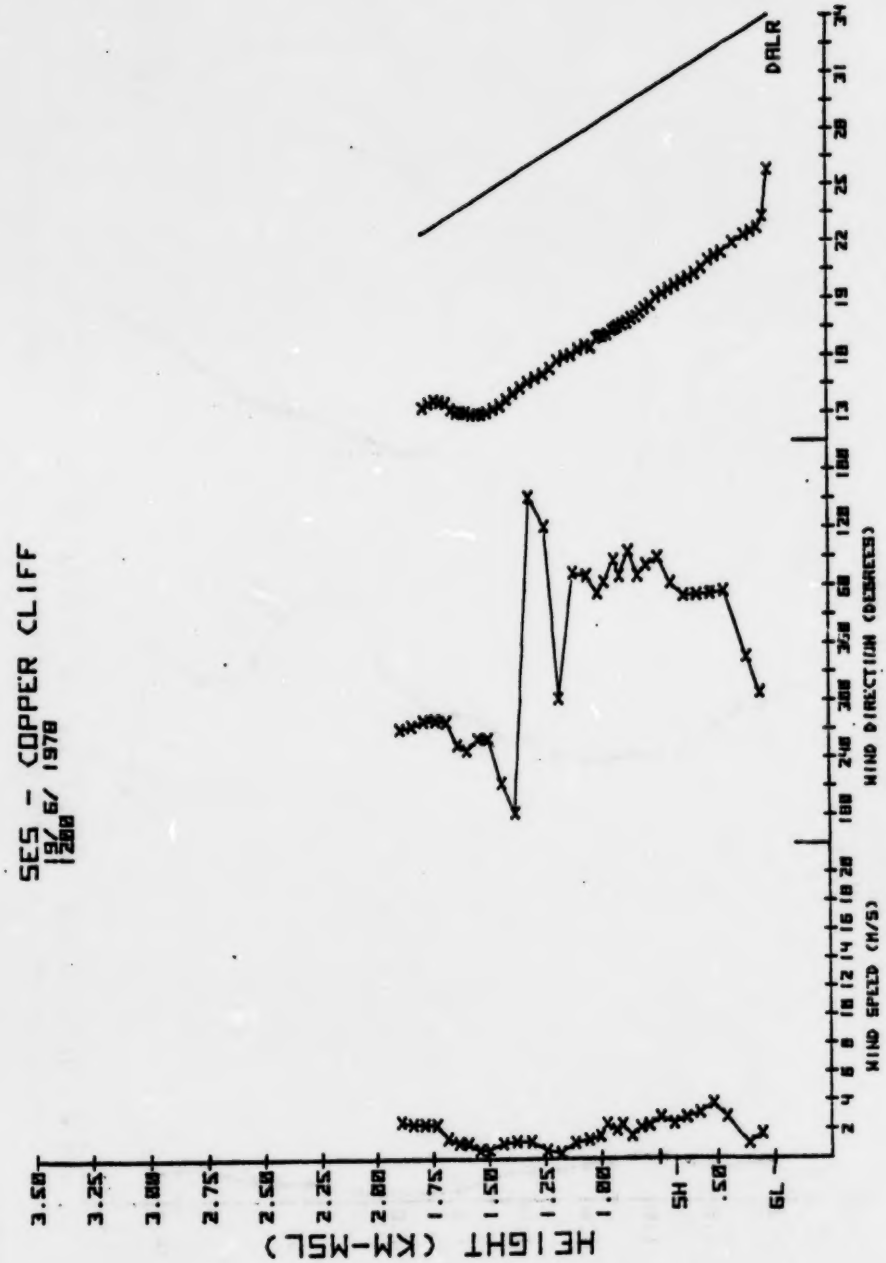

SES - COPPER CLIFF
15/6/ 1978
1600
HEIGHT (KM-MSL)
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
SH
.50
GL
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG C)

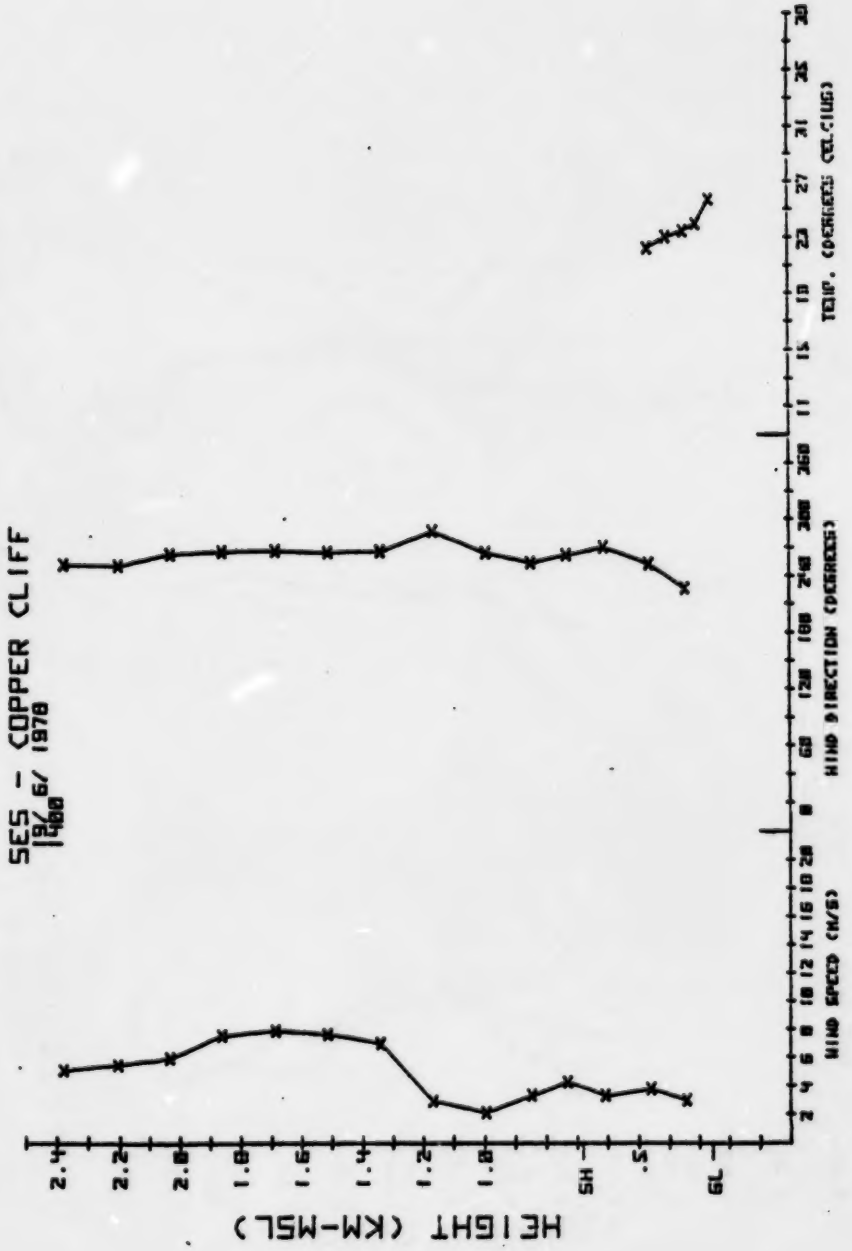

SES - COPPER CLIFF
15/6/ 1978
1700
HEIGHT (KM-MSL)
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.000
SH
.50
GL
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG C)

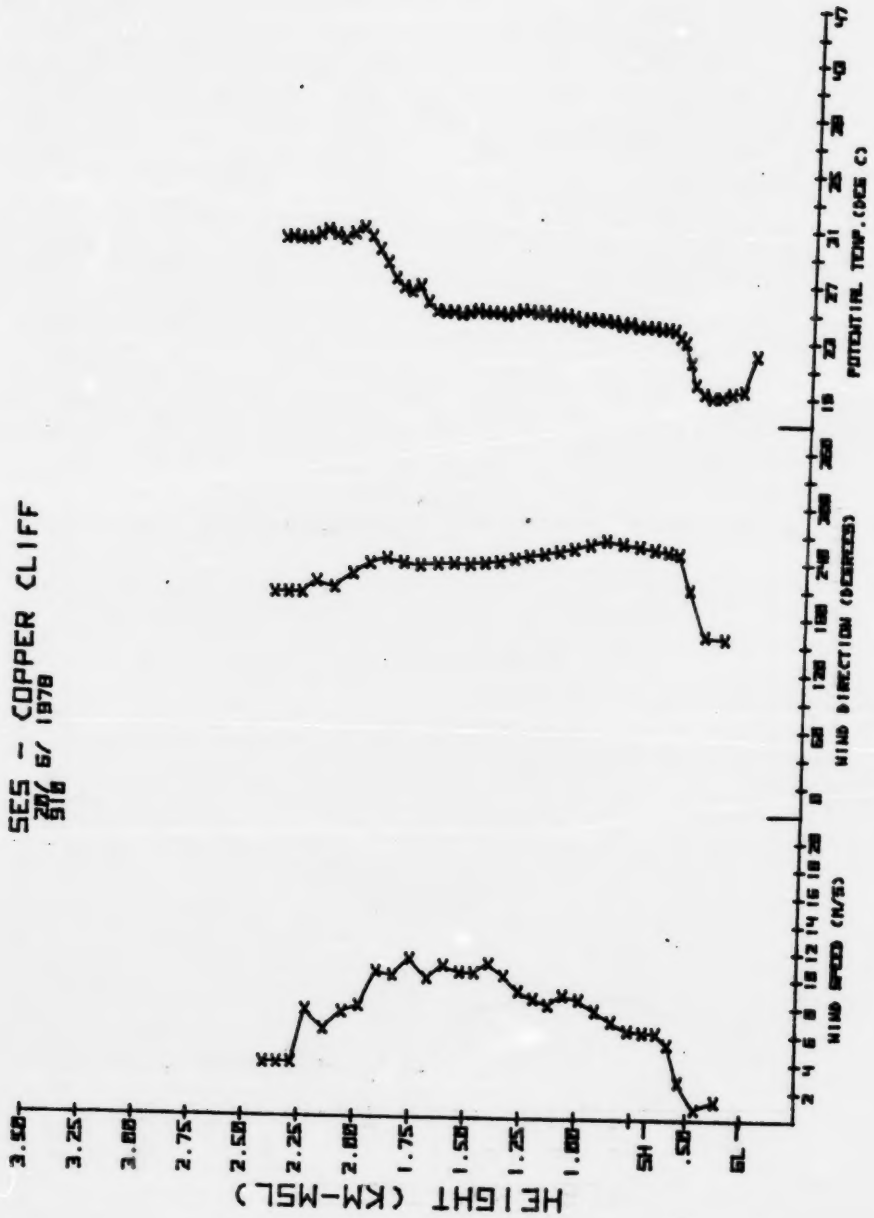

SES - COPPER CLIFF
HEIGHT (KM-MSL)

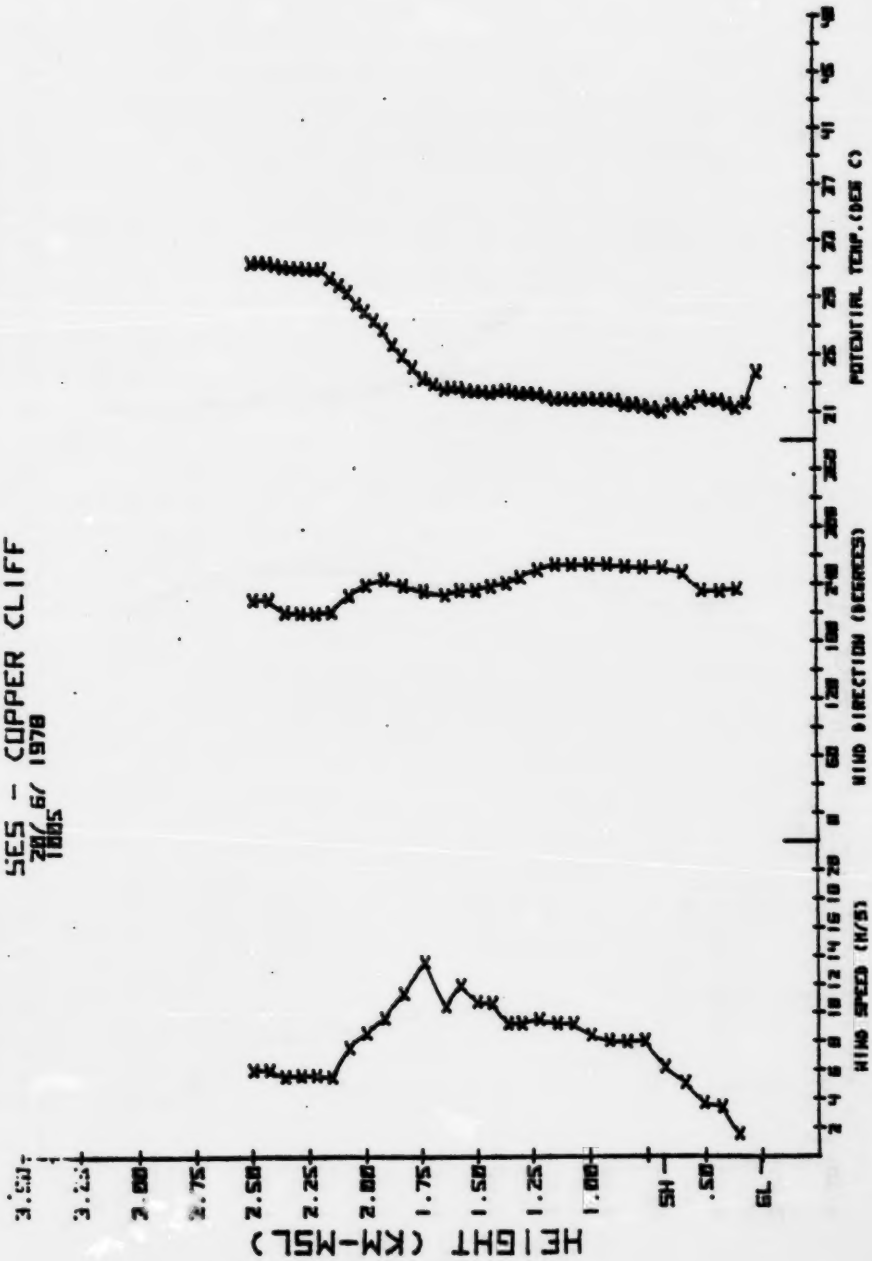

SES - COPPER CLIFF
DATE
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
TEMP. (DEGREES CELCIUS)
HEIGHT (KM-MSL)

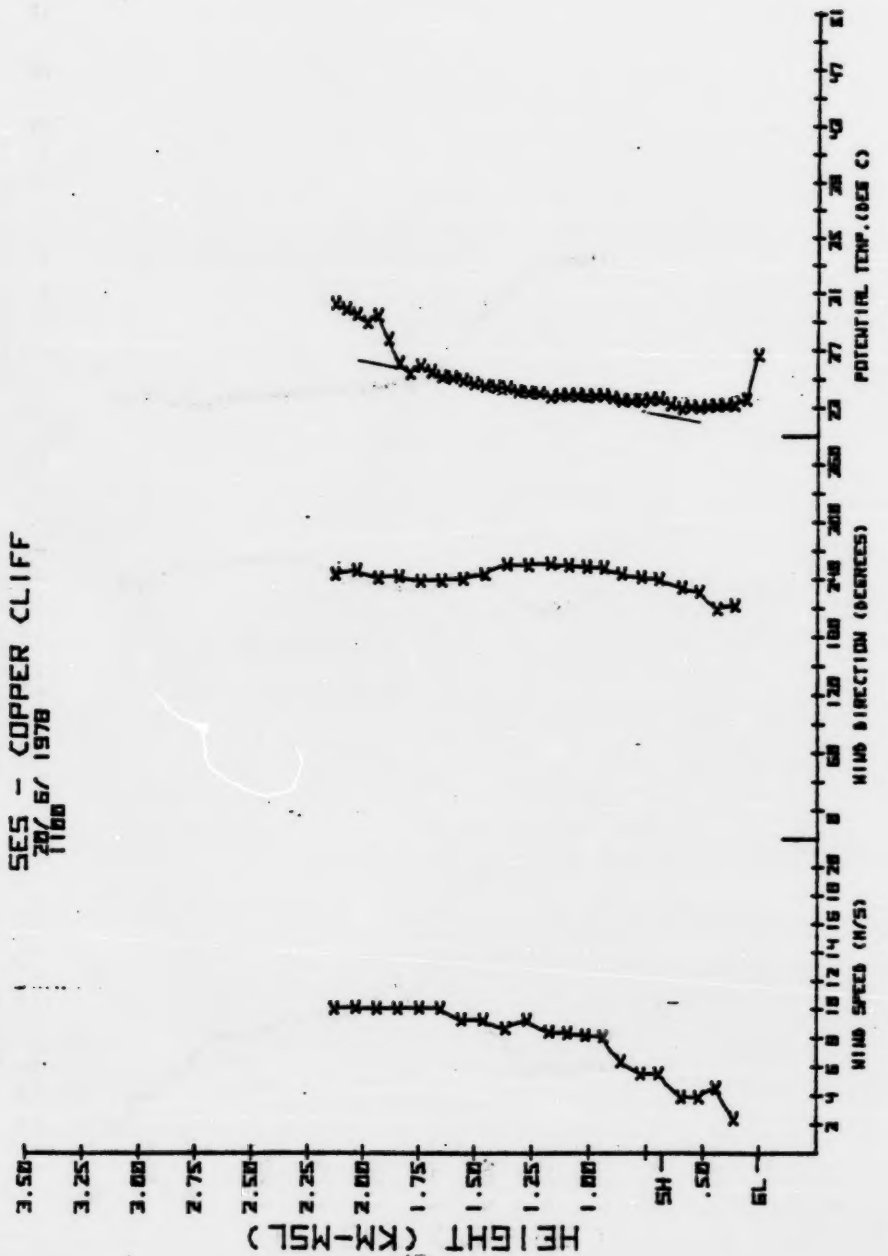

SES - COPPER CLIFF
18/ 6/ 1978
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.5
HS
GL
DALR
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
TEMP. (DEGREES CELCIUS)

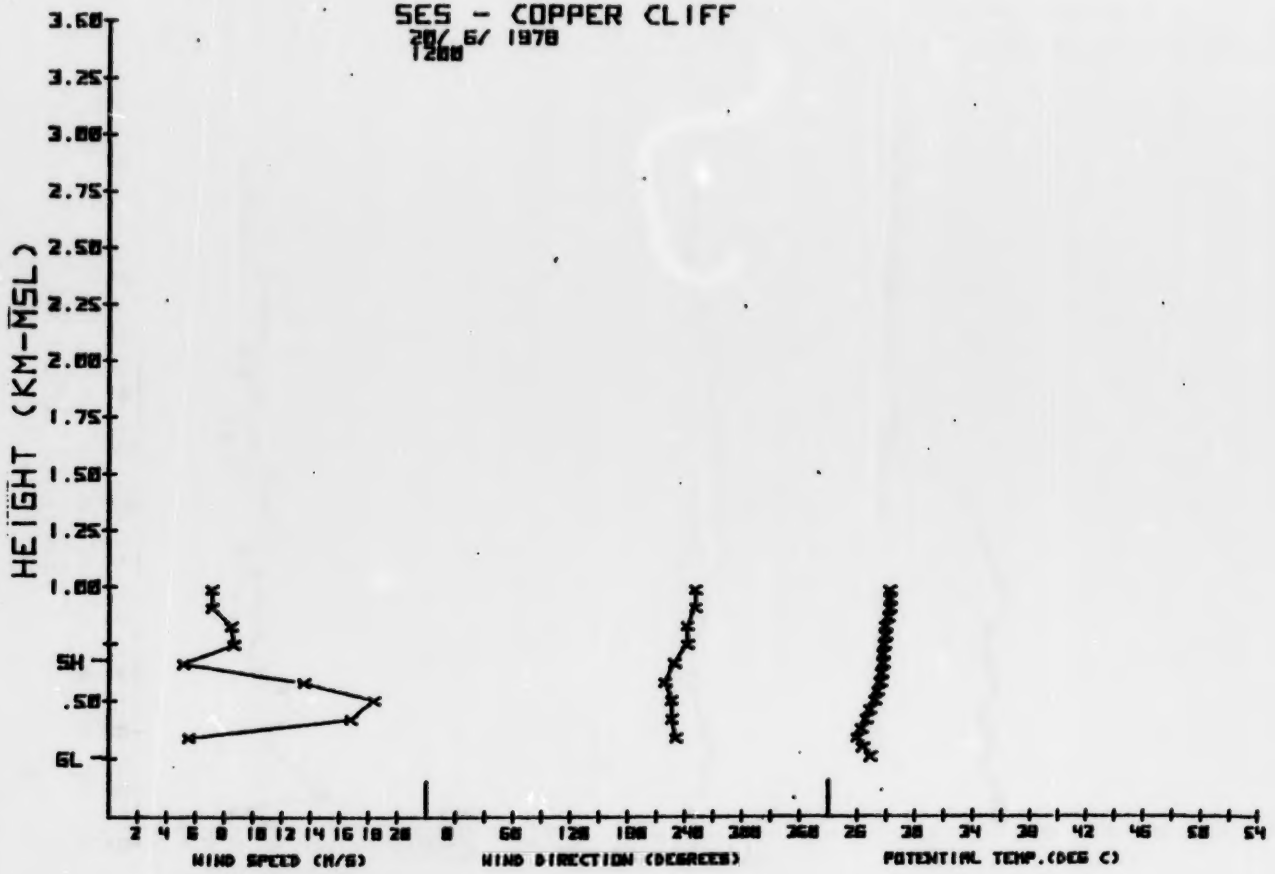

SES - COPPER CLIFF
18/ 6/ 1978
1200
HEIGHT (KM-MSL)
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
.50
SH
GL
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
DALR

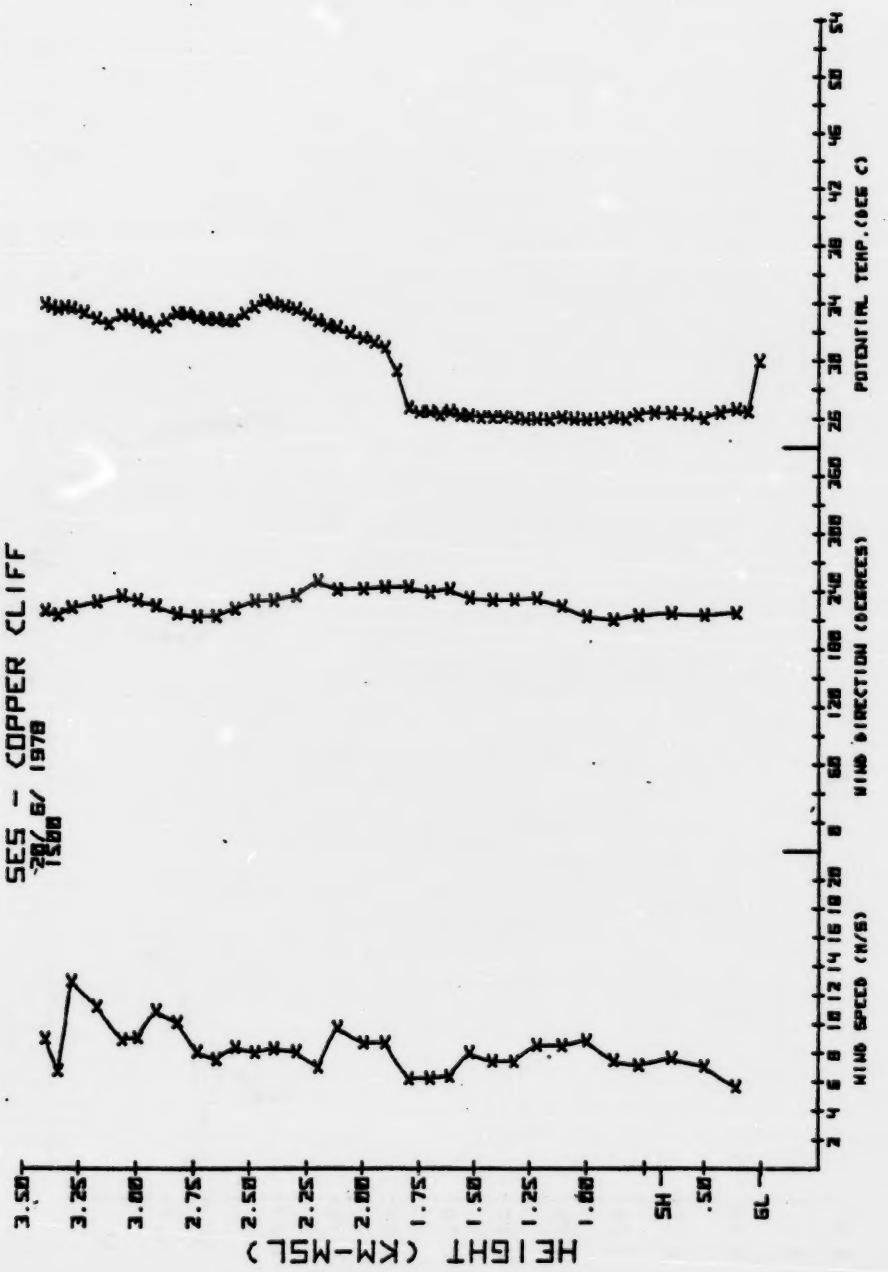

SES - COPPER CLIFF
18/6/ 1978
1400
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
SH
GL
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
TEMP. (DEGREES CELSIUS)

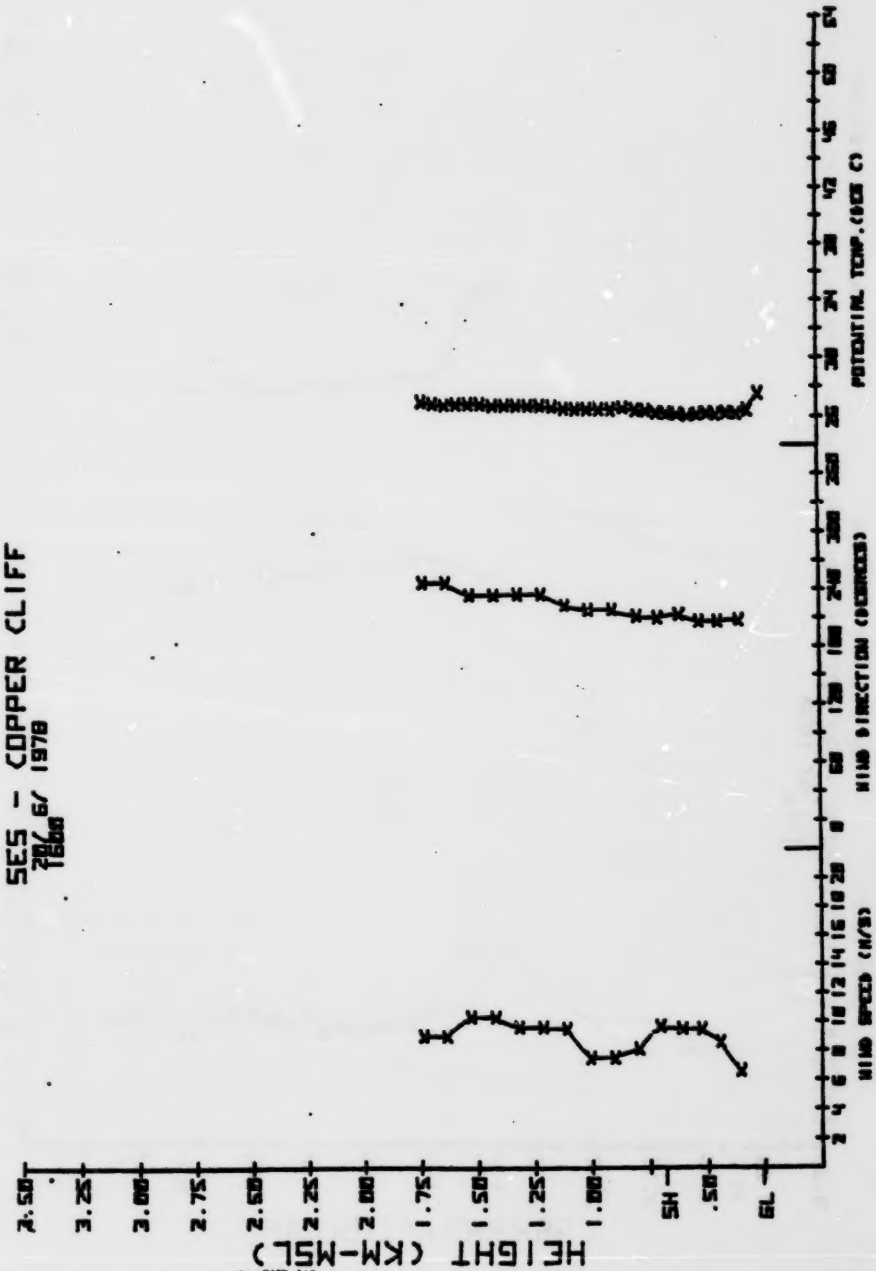

SES - COPPER CLIFF
20/ 6/ 1978
518
HEIGHT (KM-MSL)
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
.50
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP.(DEG C)

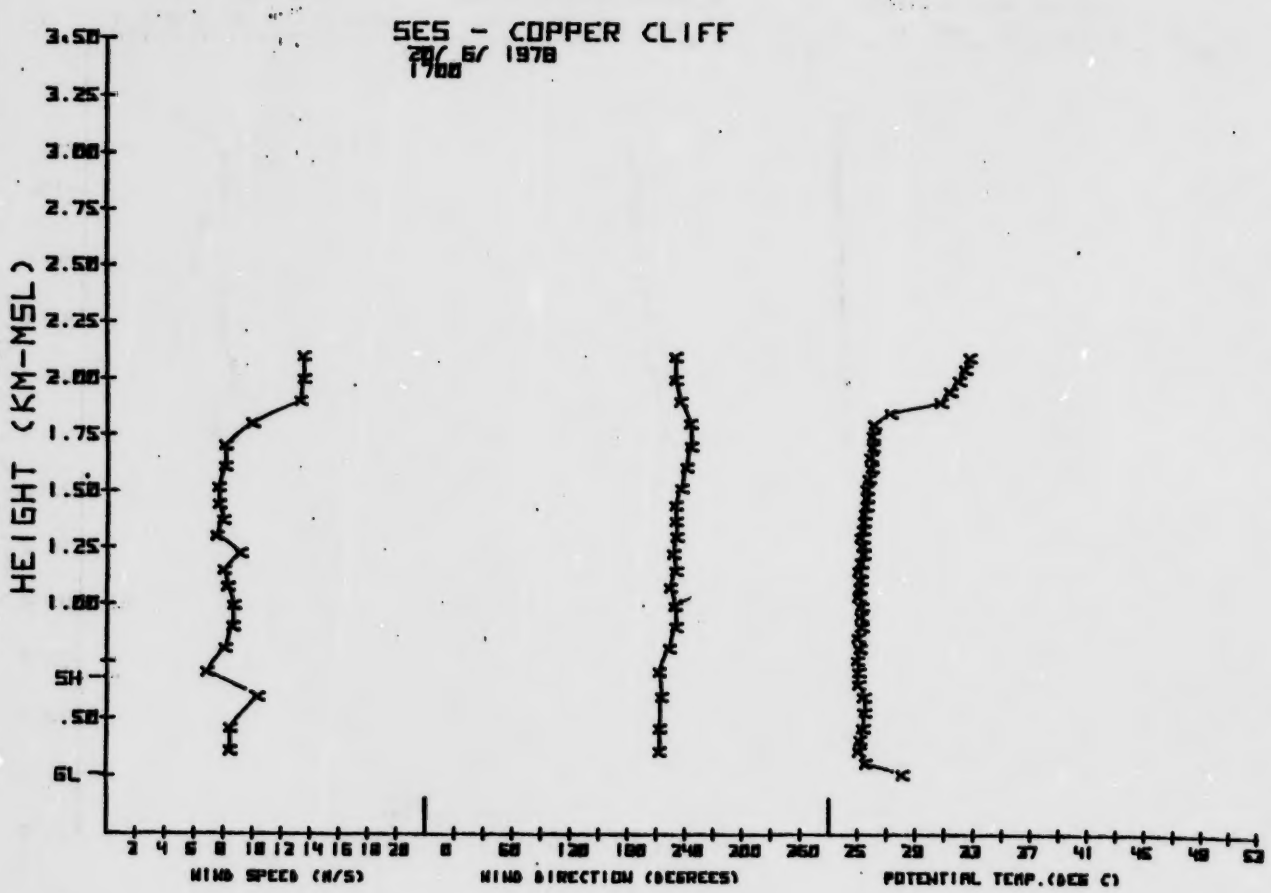

SES - COPPER CLIFF
28/ 6/ 1978
18UTC
HEIGHT (KM-MSL)
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP.(DEG C)

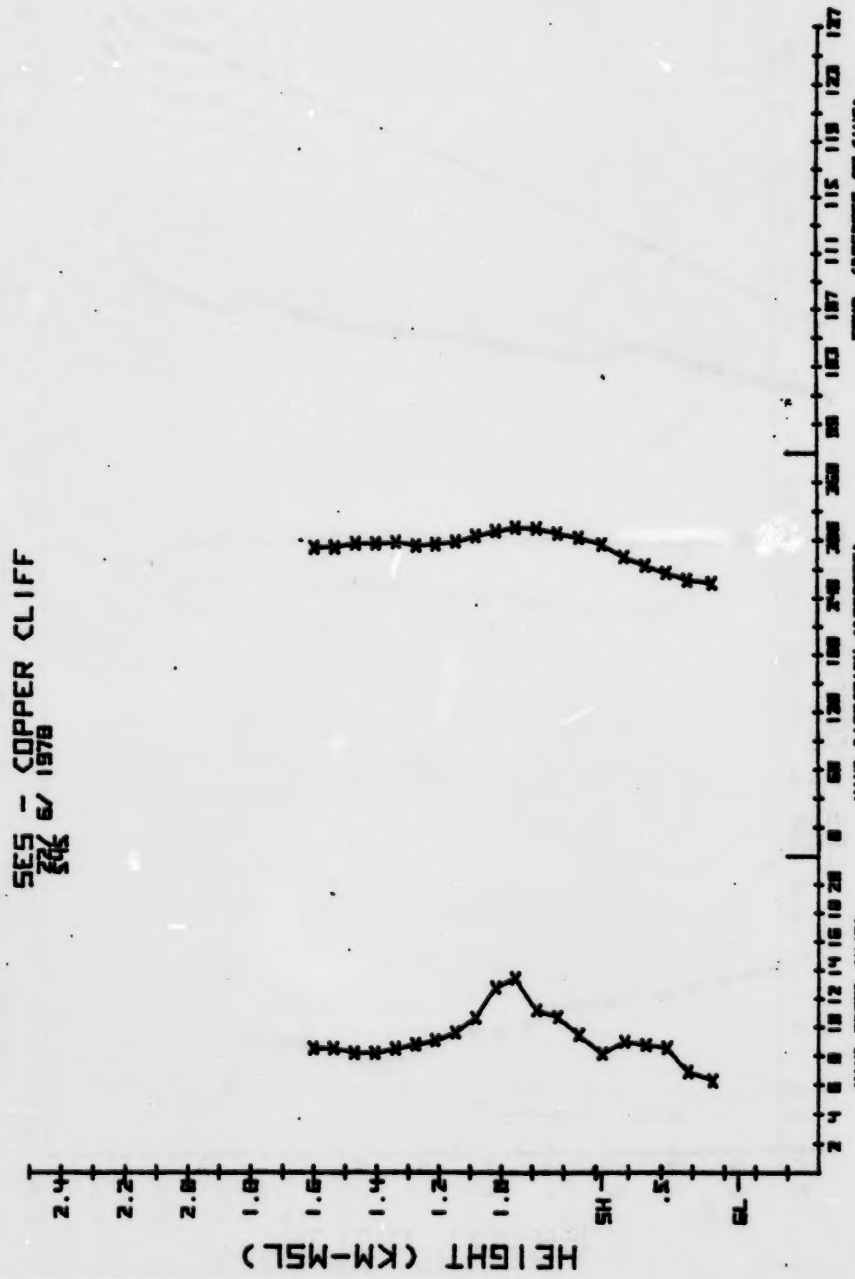

SES - COPPER CLIFF
20/6/ 1978
1100
HEIGHT (KM-MSL)
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
.50
HS
SL
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP.(DEG C)

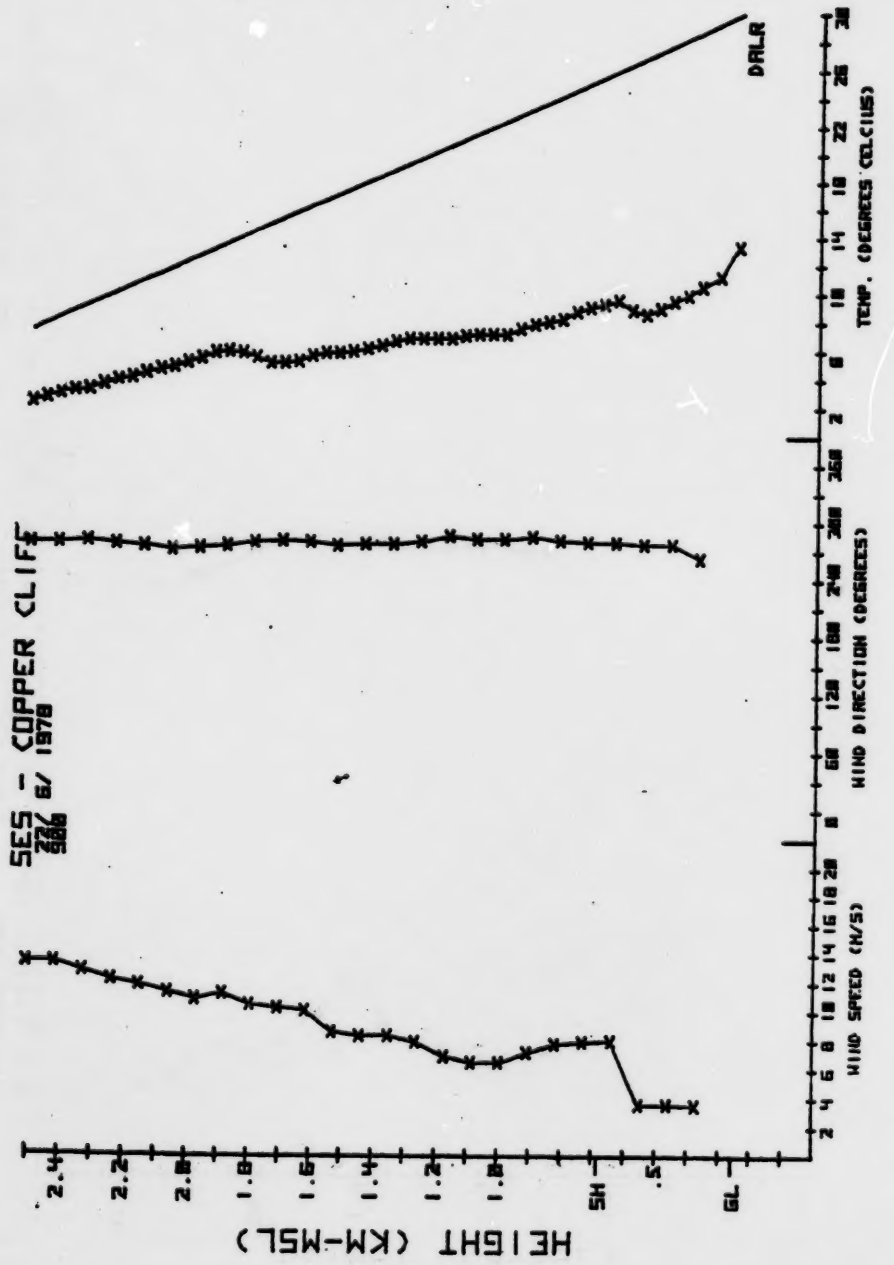

SES - COPPER CLIFF
20/ 6/ 1978
1200
HEIGHT (KM-MSL)
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
SH
.50
GL
2 4 6 8 10 12 14 16 18 20
WIND SPEED (M/S)
0 60 120 180 240 300 360
WIND DIRECTION (DEGREES)
26 30 34 38 42 46 50 54
POTENTIAL TEMP.(DEG C)

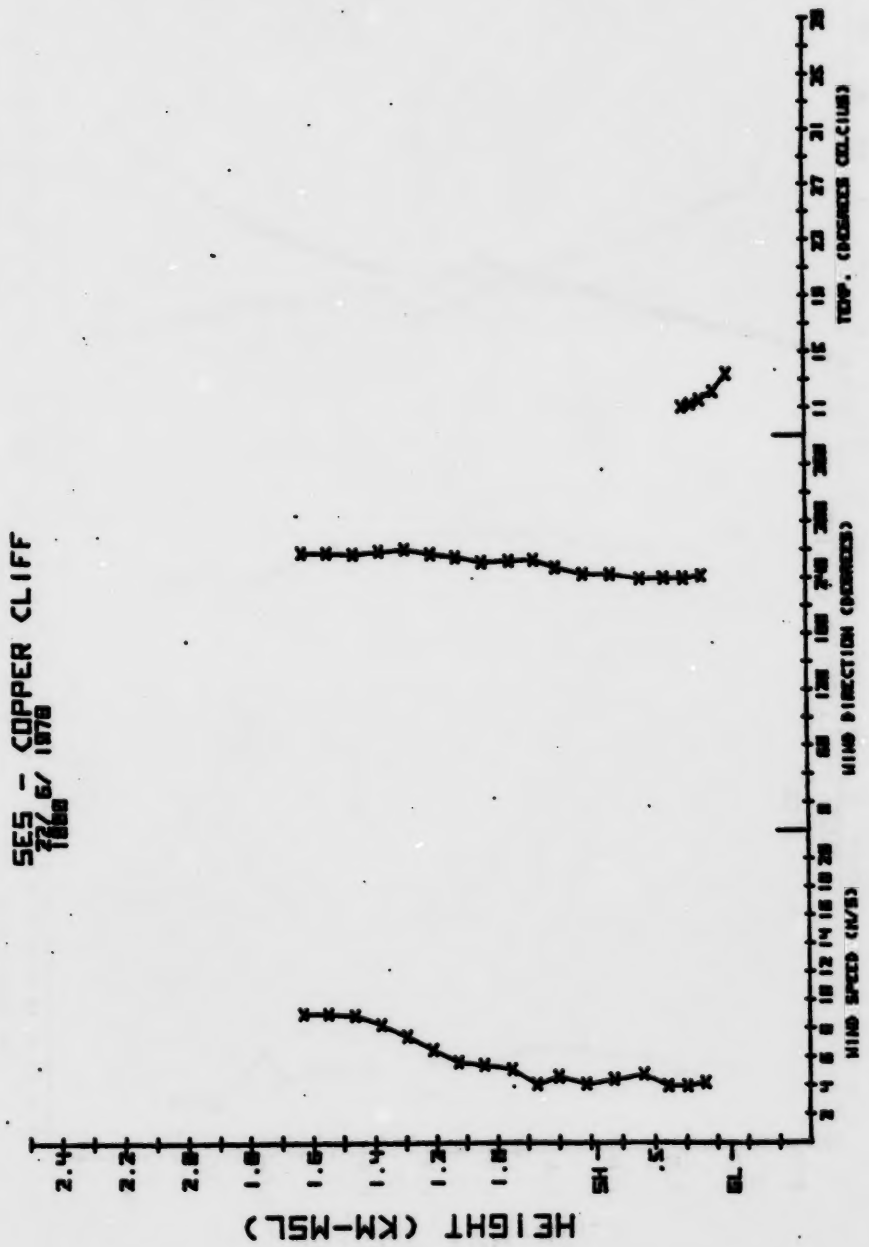

SES - COPPER CLIFF
20/ 6/ 1978
1500
HEIGHT (KM-MSL)
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
.50
SH
SL
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP.(DEG C)

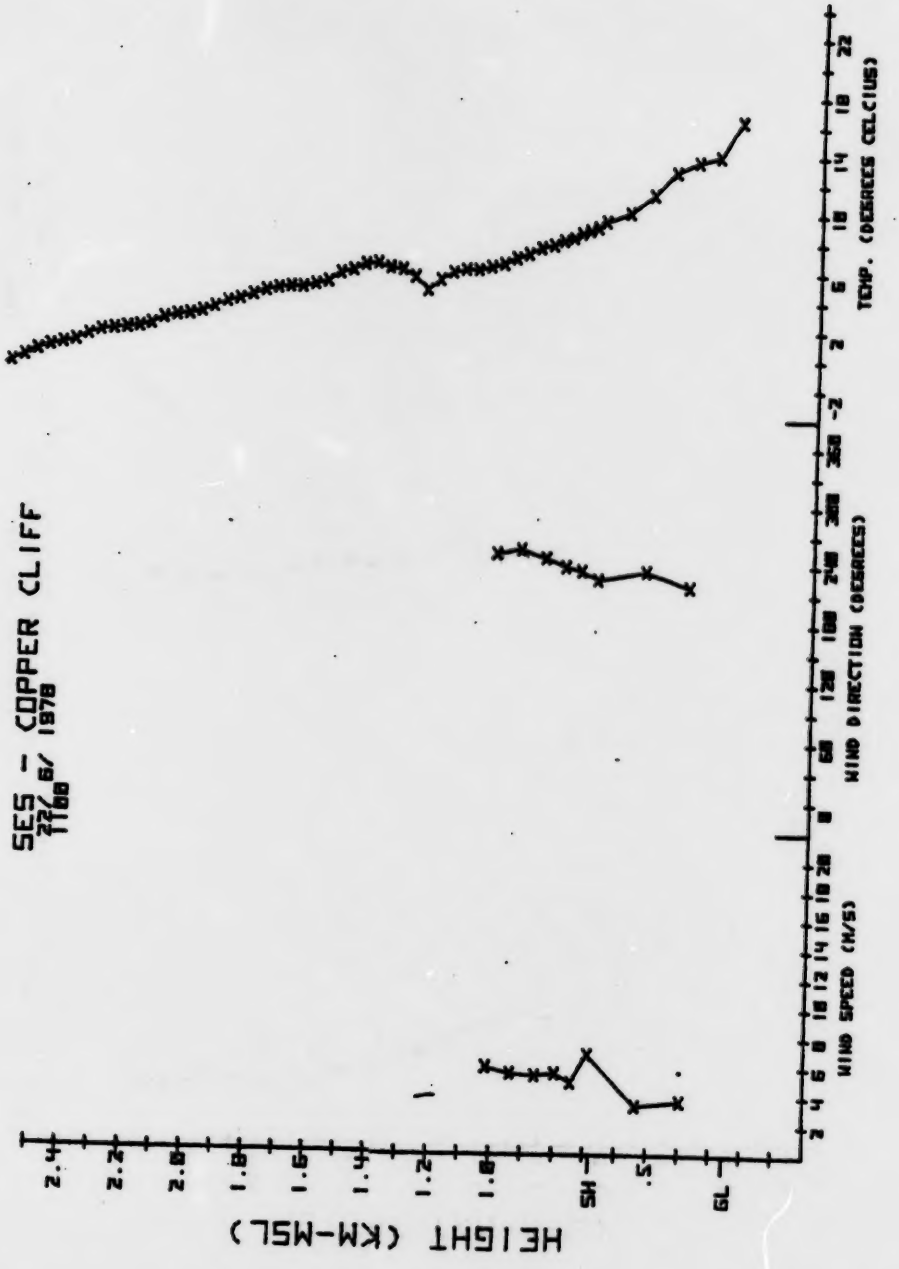

SES - COPPER CLIFF
27/6/ 1978
1800
HEIGHT (KM-MSL)
2.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
.75
.50
.25
SL
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG C)

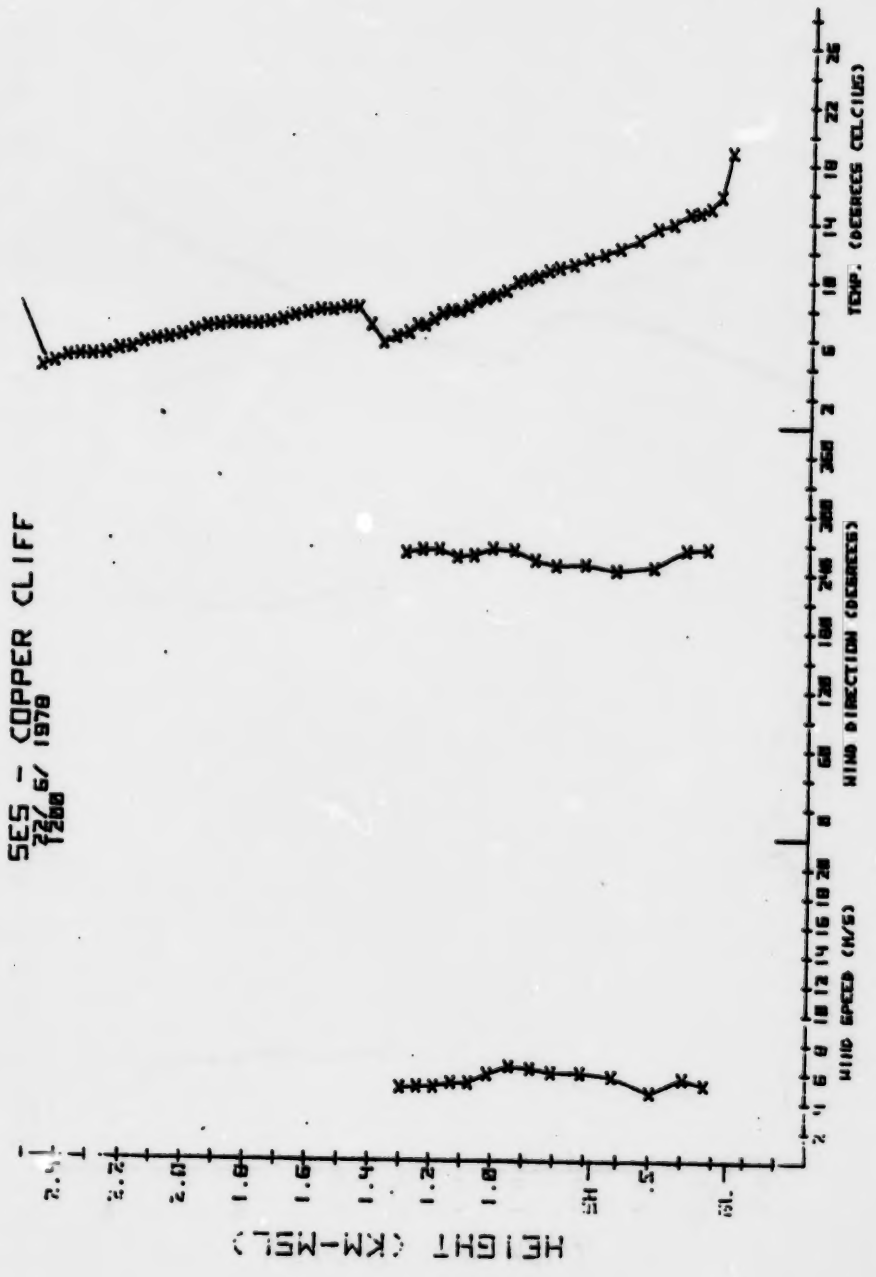

SES - COPPER CLIFF
20/ 6/ 1978
1700
HEIGHT (KM-MSL)
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
SH
.50
GL
2 4 6 8 10 12 14 16 18 20
WIND SPEED (M/S)
0 60 120 180 240 300 360
WIND DIRECTION (DEGREES)
25 29 33 37 41 45 49 53
POTENTIAL TEMP. (DEG C)

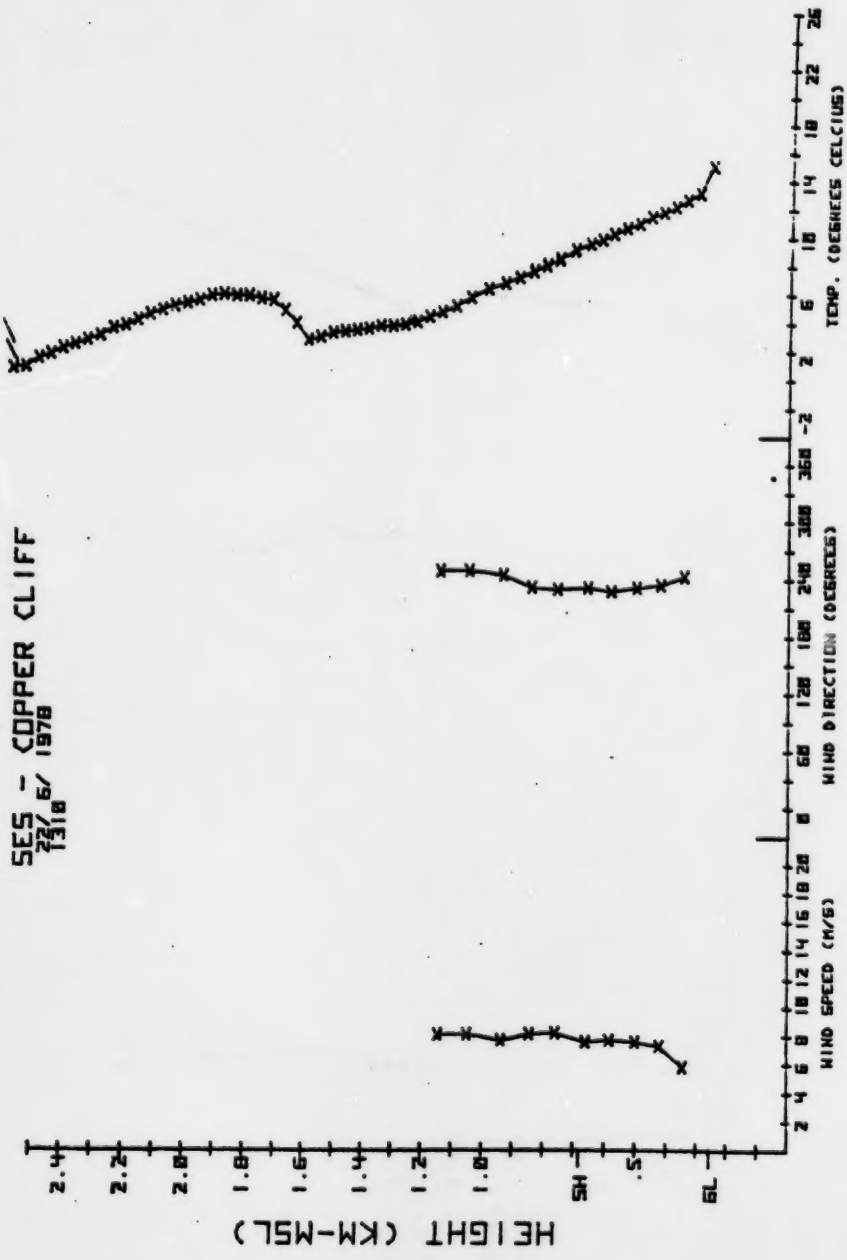

SES - COPPER CLIFF
22/6/78
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.5
HS
TG
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
TEMP. (DEGREES CELCIUS)

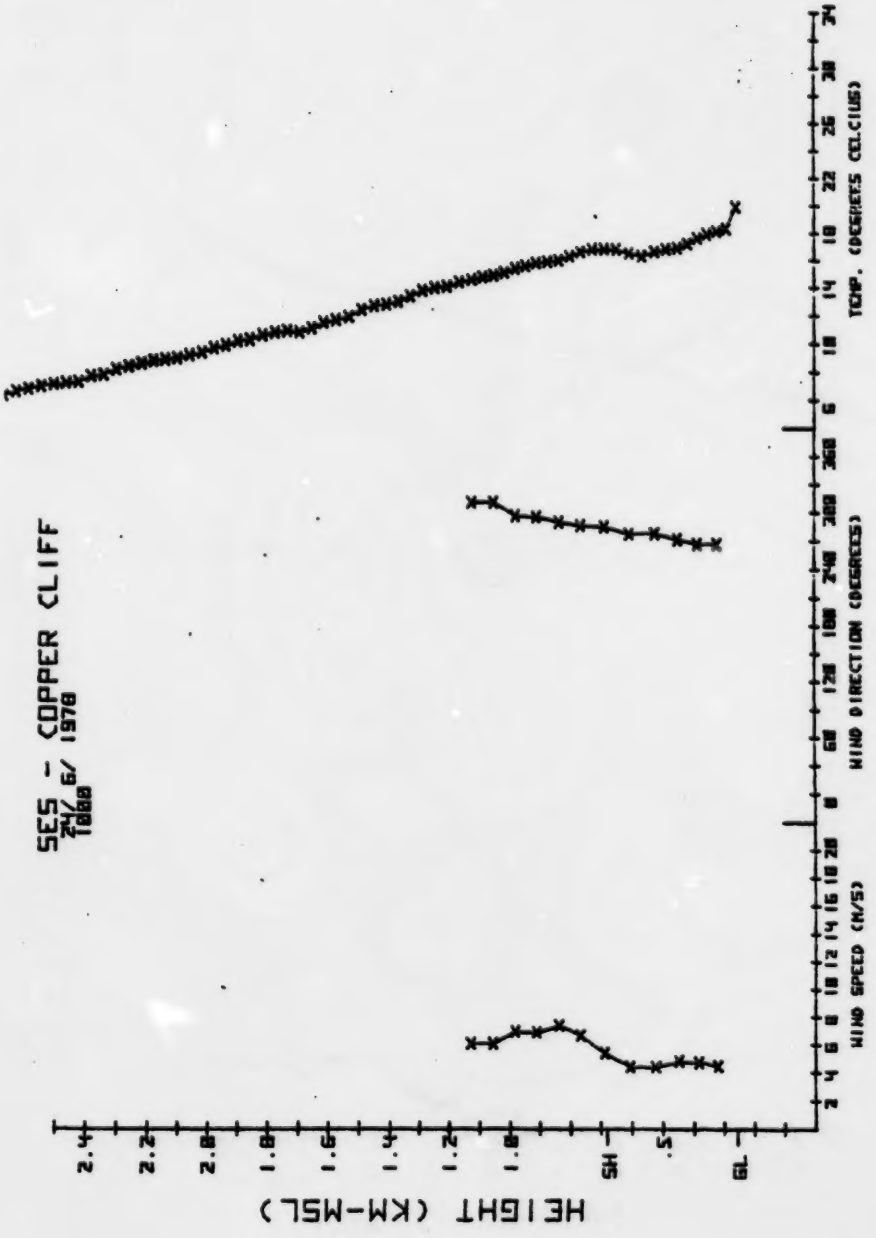

SES - COPPER CLIFF
226
586 6/ 1978
DALR
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.5
HS
GL
WIND SPEED (M/S)
2 4 6 8 10 12 14 16 18 20
WIND DIRECTION (DEGREES)
0 60 120 180 240 300 360
TEMP. (DEGREES CELCIUS)
2 6 10 14 18 22 26 30

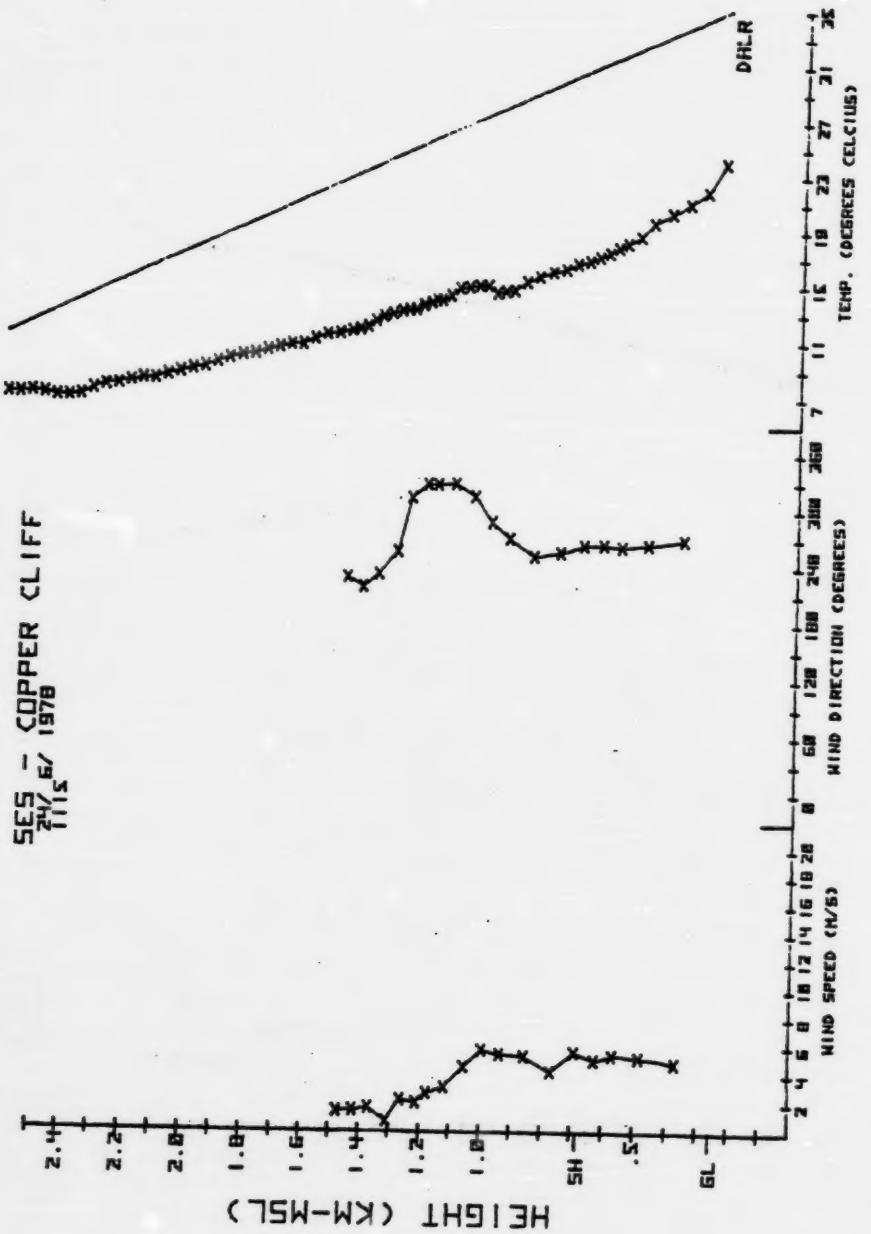

SES - COPPER CLIFF
HEIGHT (KM-MSL)
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
TEMP. (DEGREES CELCIUS)

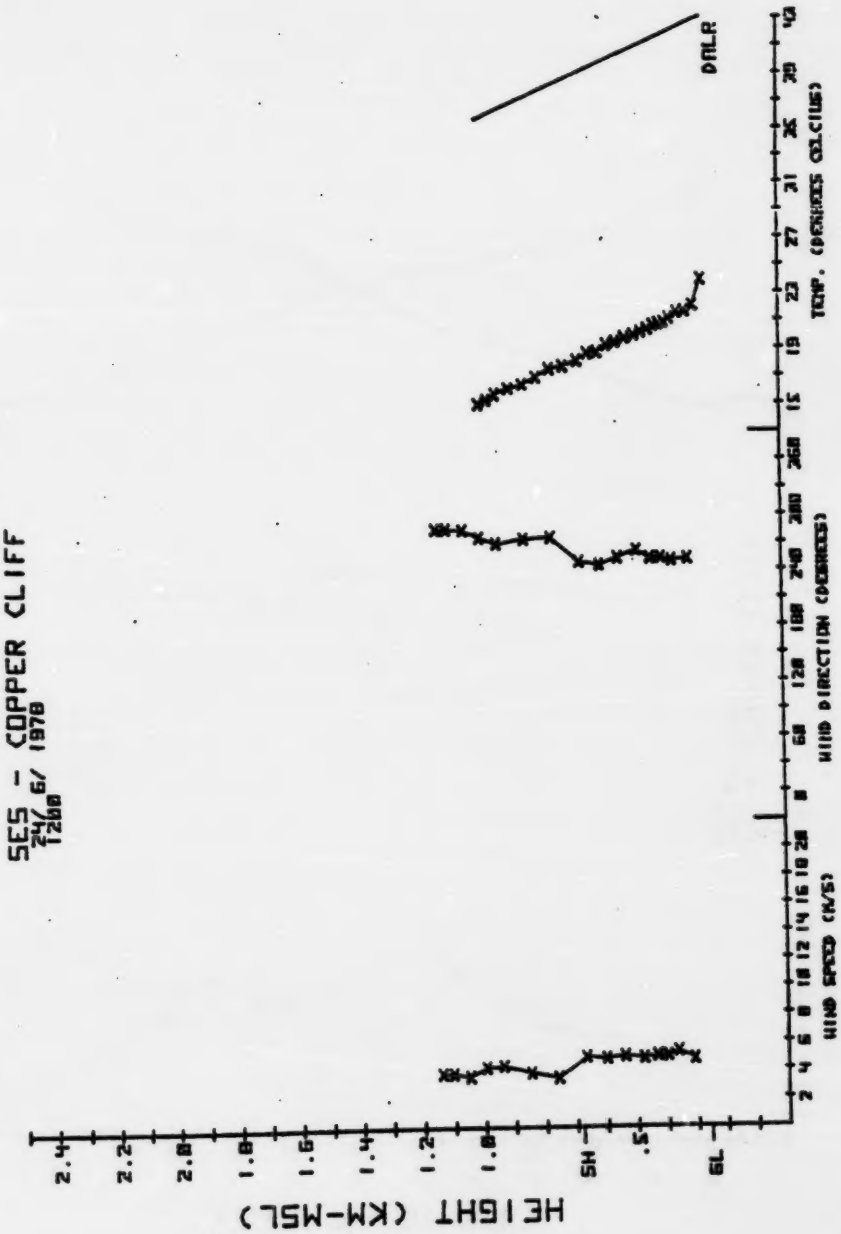

SES - COPPER CLIFF
22/ 6/ 1978
1168
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.5
HS
GL
WIND SPEED (M/S)
2 4 6 8 10 12 14 16 18 20
WIND DIRECTION (DEGREES)
0 60 120 180 240 300 360
TEMP. (DEGREES CELCIUS)
-2 2 6 10 14 18 22

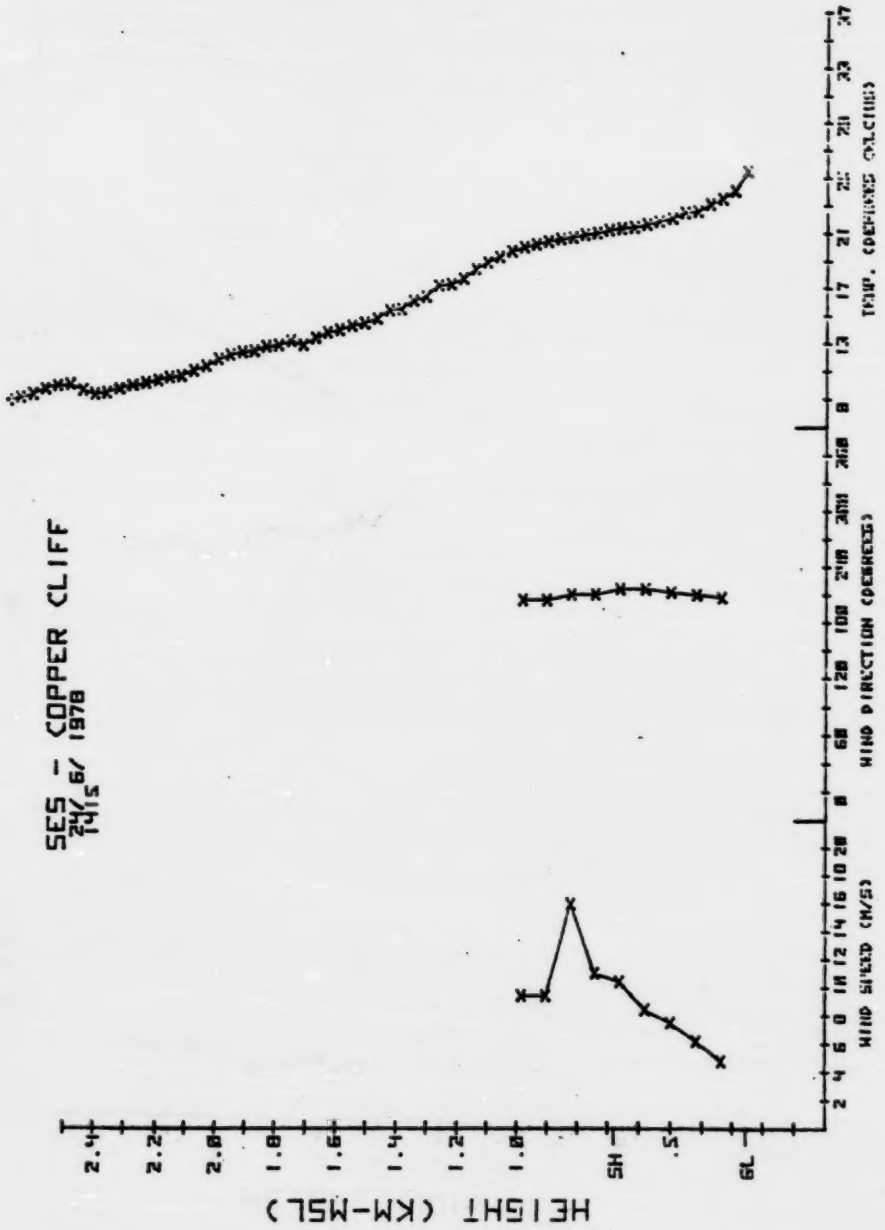

SES - COPPER CLIFF
27/ 6/ 1978
1200
HEIGHT (KM-MSL)
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
TEMP. (DEGREES CELCIUS)

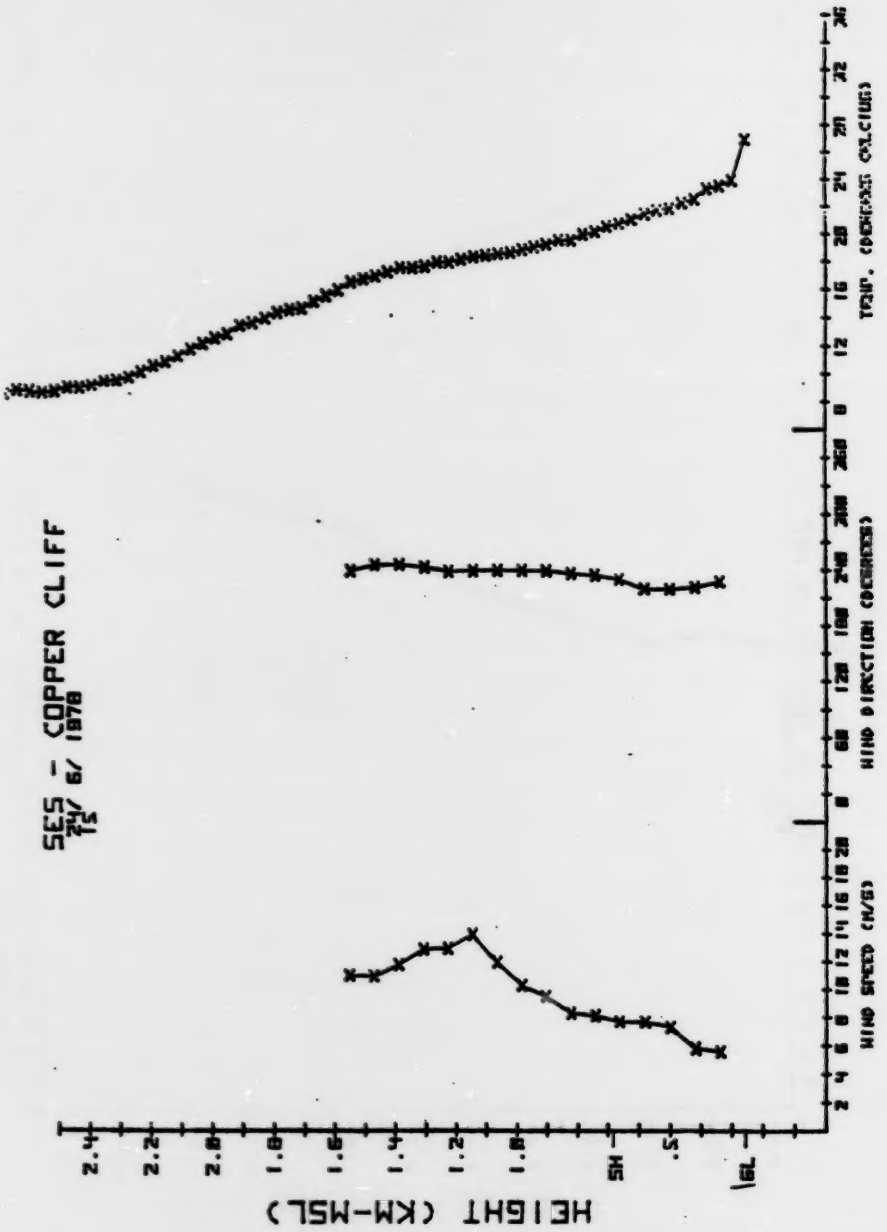

SES - COPPER CLIFF
27/ 6/ 1978
1318
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.5
HS
TG
WIND SPEED (M/S)
2 4 6 8 10 12 14 16 18 20
WIND DIRECTION (DEGREES)
0 60 120 180 240 300 360
TEMP. (DEGREES CELCIUS)
-2 2 6 10 14 18 22 26

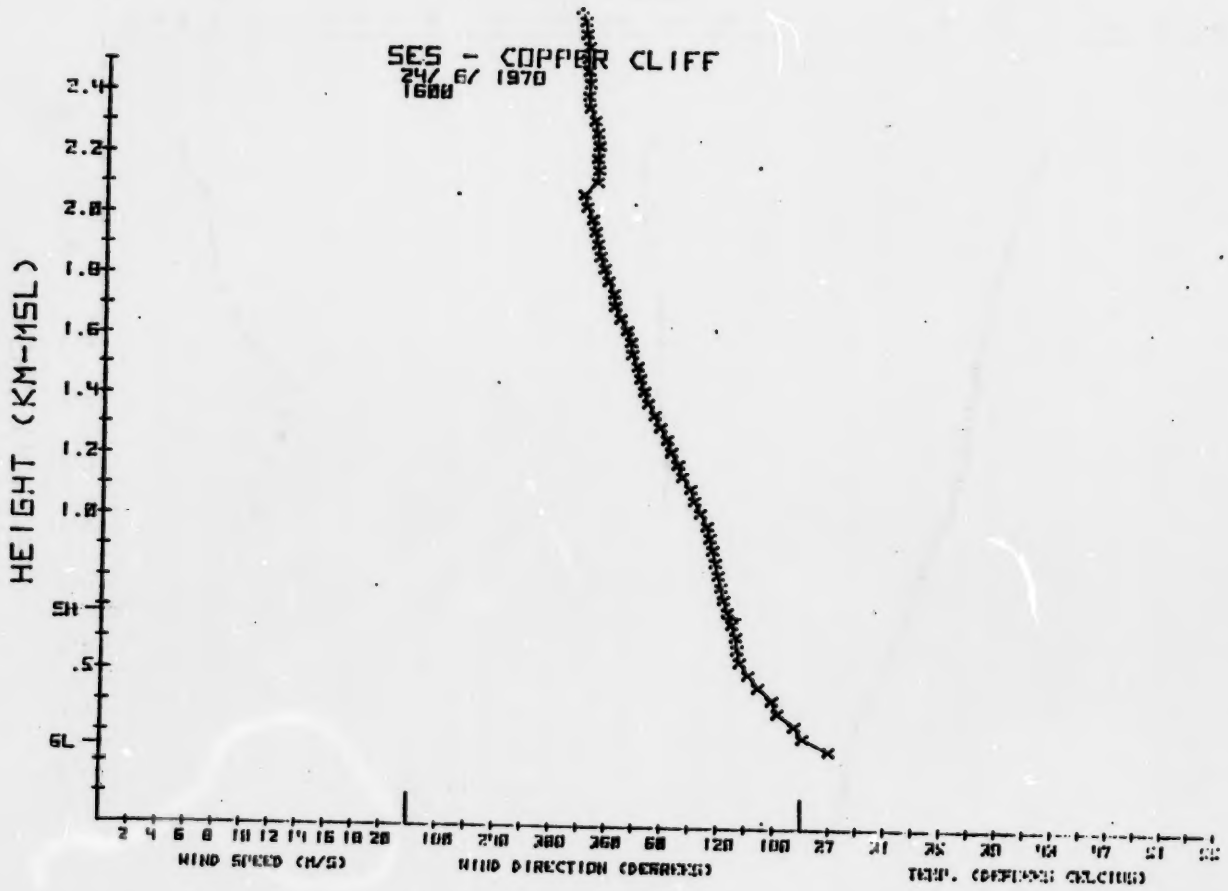

SES - COPPER CLIFF
24/ 6/ 1978
1800
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
SH
GL
WIND SPEED (M/S)
2 4 6 8 10 12 14 16 18 20
0 60 120 180 240 300 360
WIND DIRECTION (DEGREES)
6 10 14 18 22 26 30 34
TEMP. (DEGREES CELCIUS)

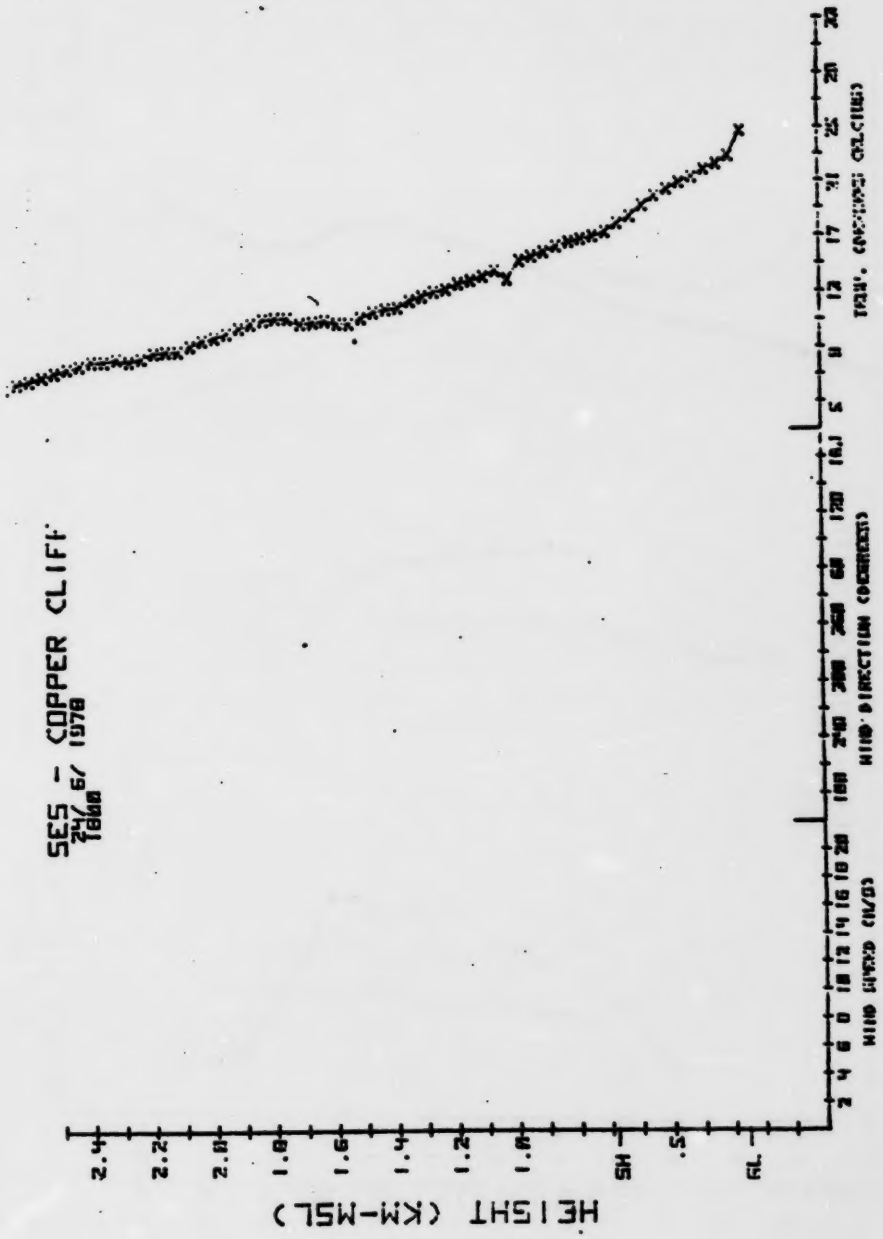

SES - COPPER CLIFF
24/ 6/ 1978
1115
DALR
TEMP. (DEGREES CELCIUS)
WIND DIRECTION (DEGREES)
WIND SPEED (M/S)
HEIGHT (KM-MSL)
GL
HS
SH

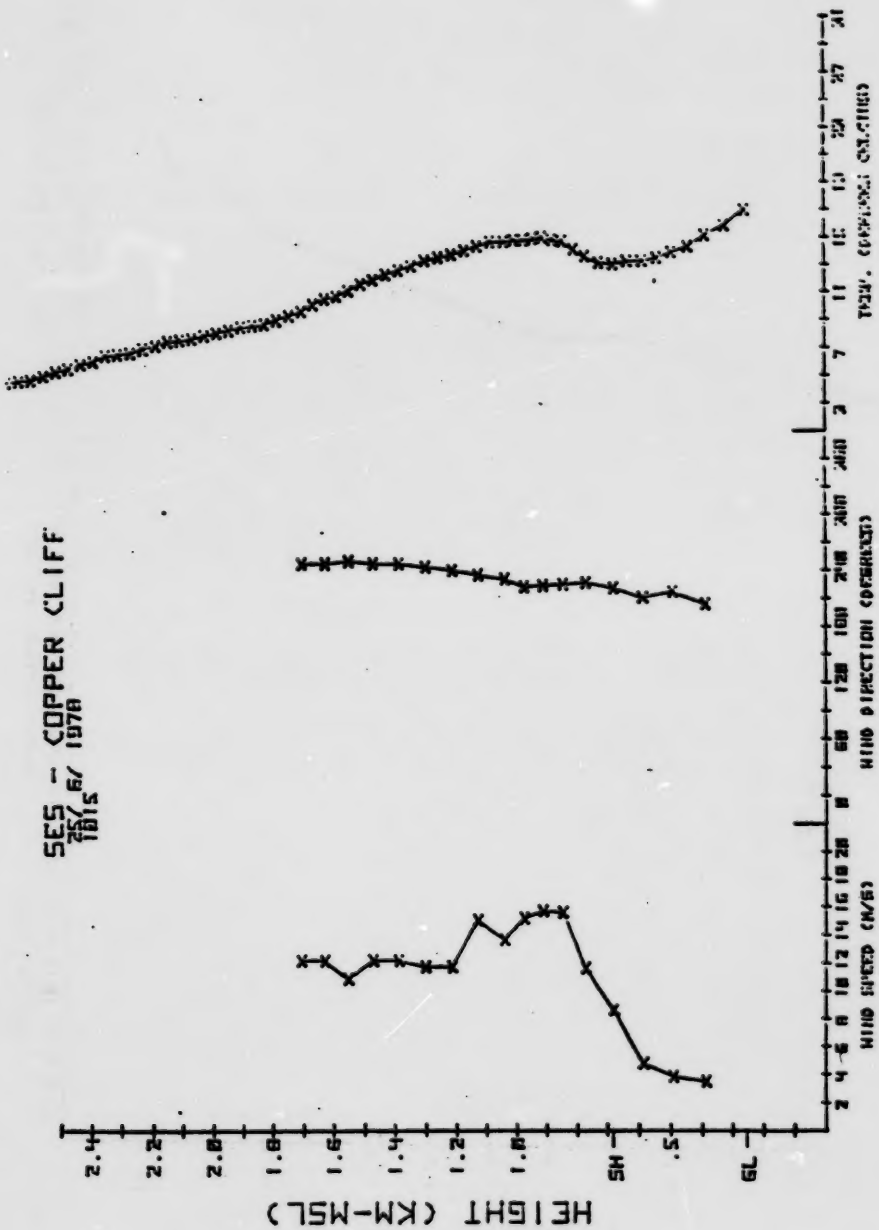

SES - COPPER CLIFF
24/ 6/ 1978
1200
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.5
SH
SL
WIND SPEED (M/S)
2 4 6 8 10 12 14 16 18 20
WIND DIRECTION (DEGREES)
0 60 120 180 240 300 360
TEMP. (DEGREES CELCIUS)
15 19 23 27 31 35 39
DALR

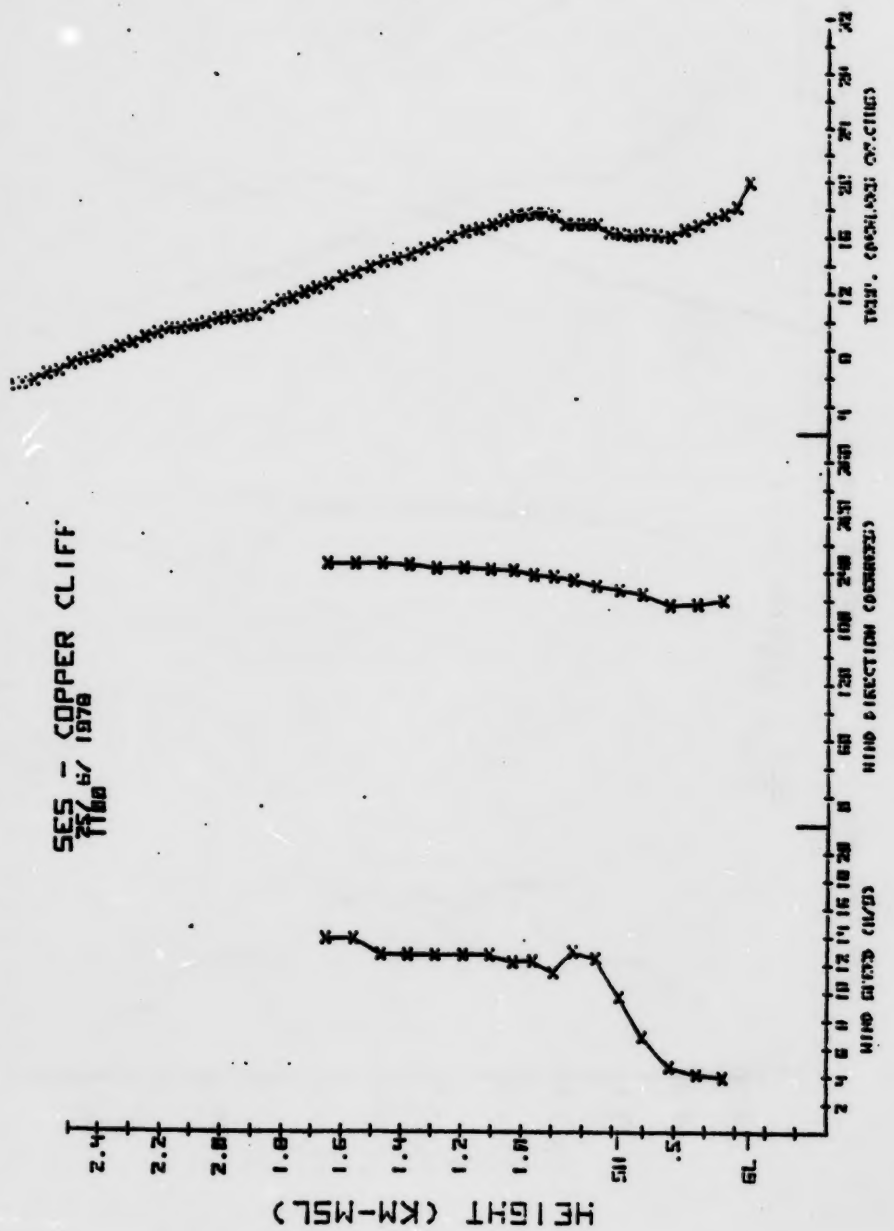

SES - COPPER CLIFF
24/6/ 1978
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.5
HS
GL
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
TEMP. (DEGREES CELCIUS)

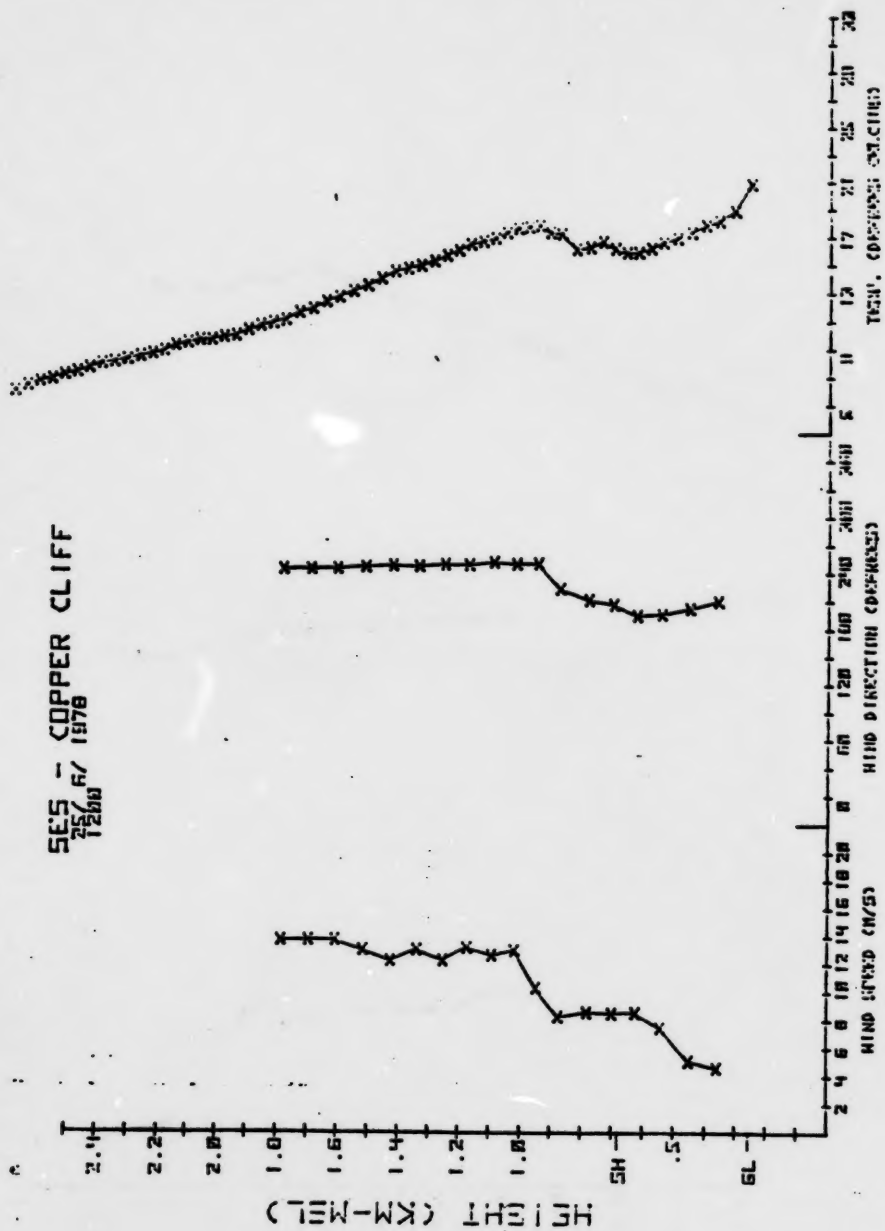

SES - COPPER CLIFF
24/ 6/ 1978
15
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.5
HS
TSL
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
TEMP. (DEGREES CELSIUS)

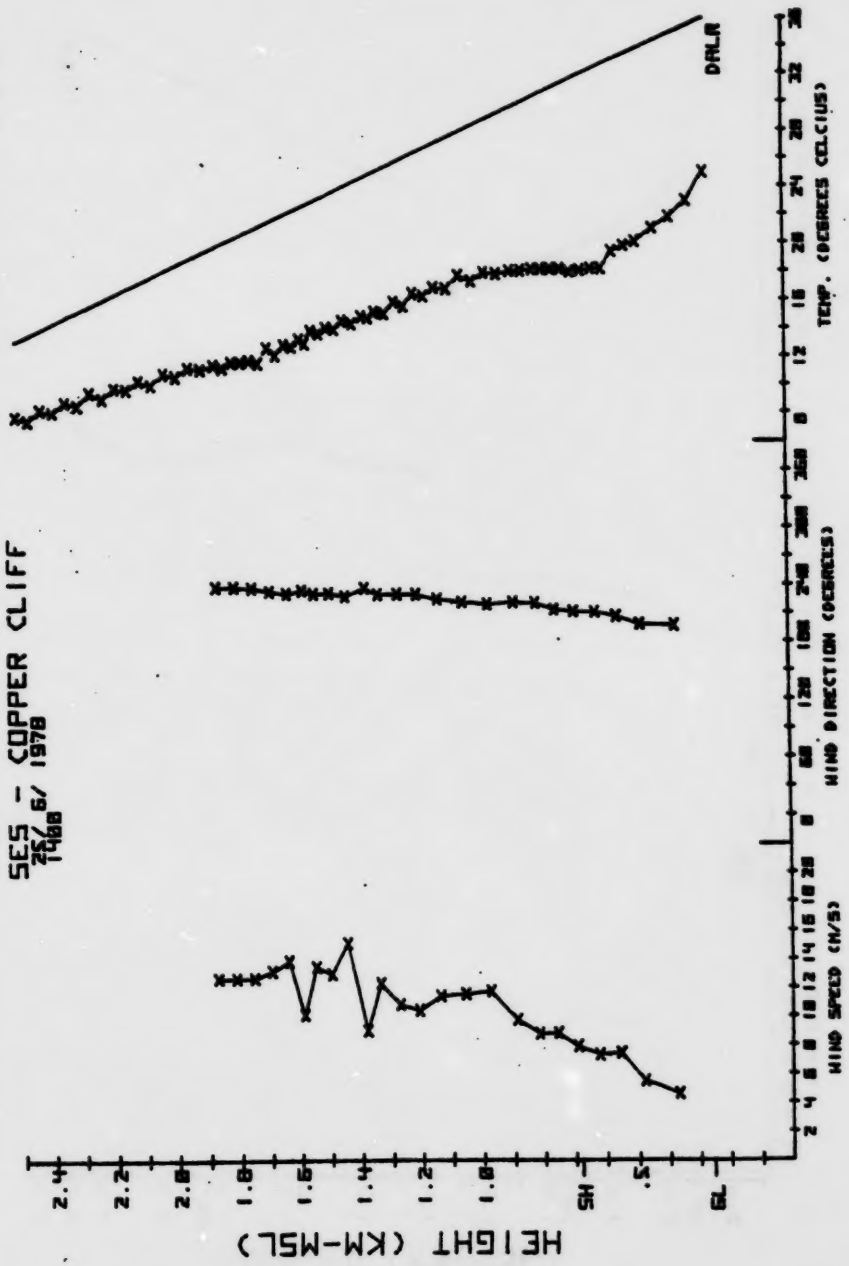

SES - COPPER CLIFF
24/ 6/ 1970
1600
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
SH
.5
GL
2 4 6 8 10 12 14 16 18 20
WIND SPEED (M/S)
108 210 300 268 60 120 180 27
WIND DIRECTION (DEGREES)


SES - COPPER CLIFF
24/ 6/ 1978
18000
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.5
SH
FL

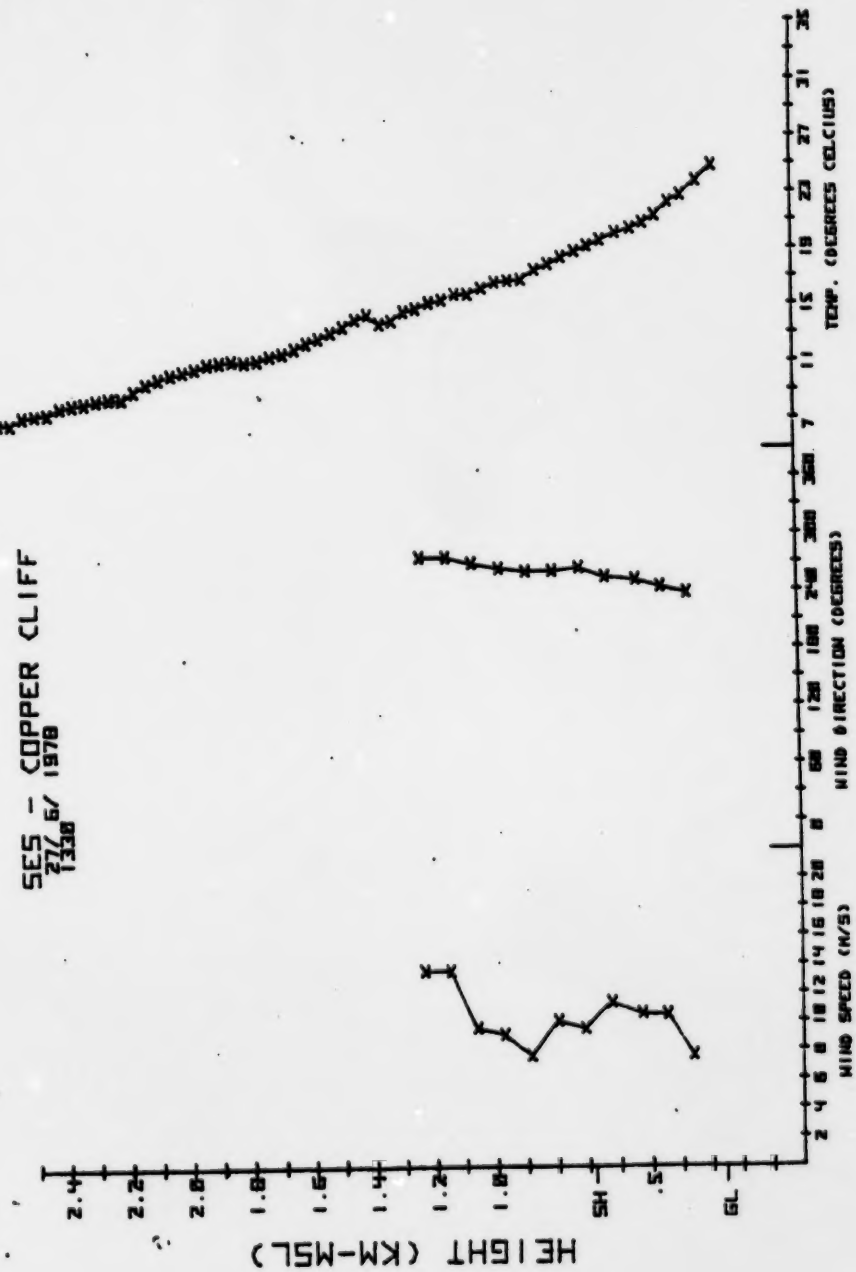

SES - COPPER CLIFF
25/ 6/ 1978
1615
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.5
MS
GL
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)


SES - COPPER CLIFF
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.5
GL

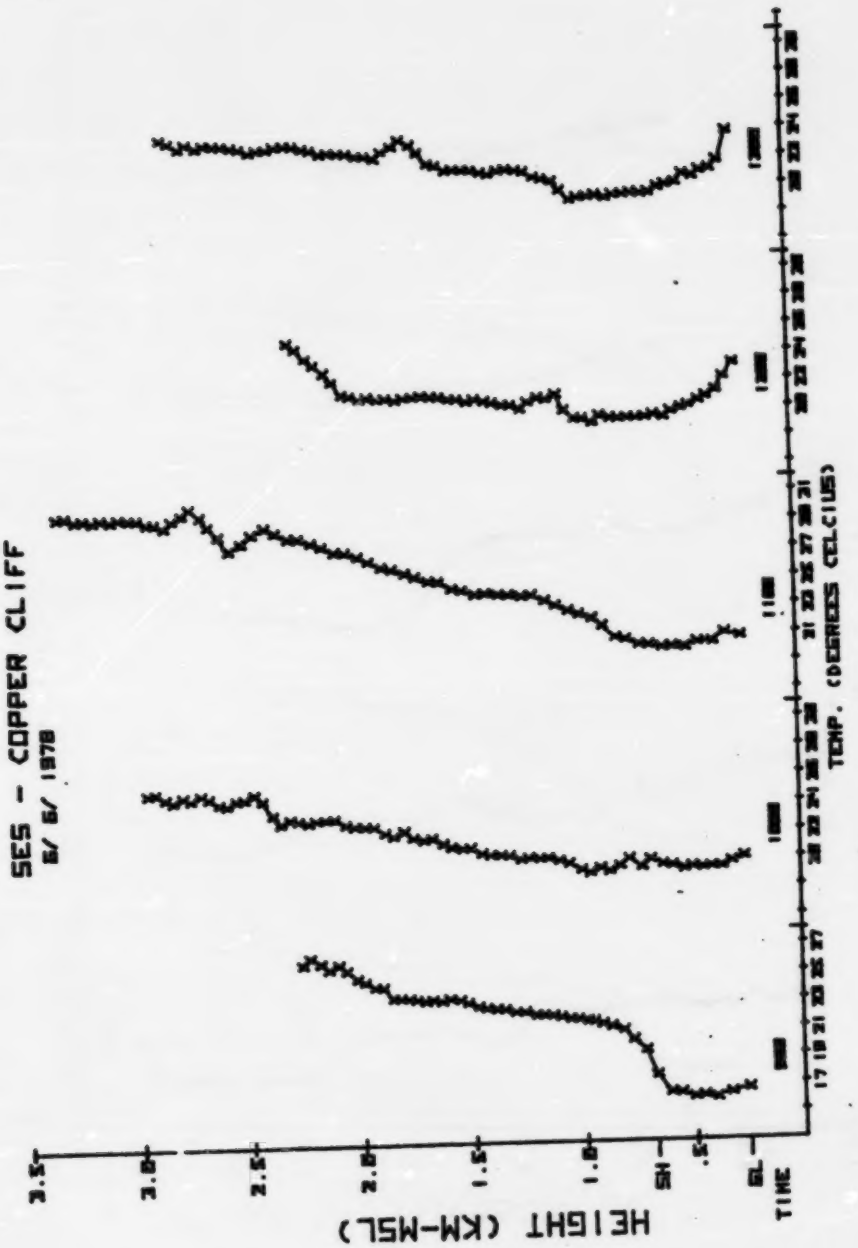

SES - COPPER CLIFF
25/ 6/ 1978
1200
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.5
SH
SL
WIND SPEED (M/S)
2 4 6 8 10 12 14 16 18 20
WIND DIRECTION (DEGREES)
0 60 120 180 240 300 360

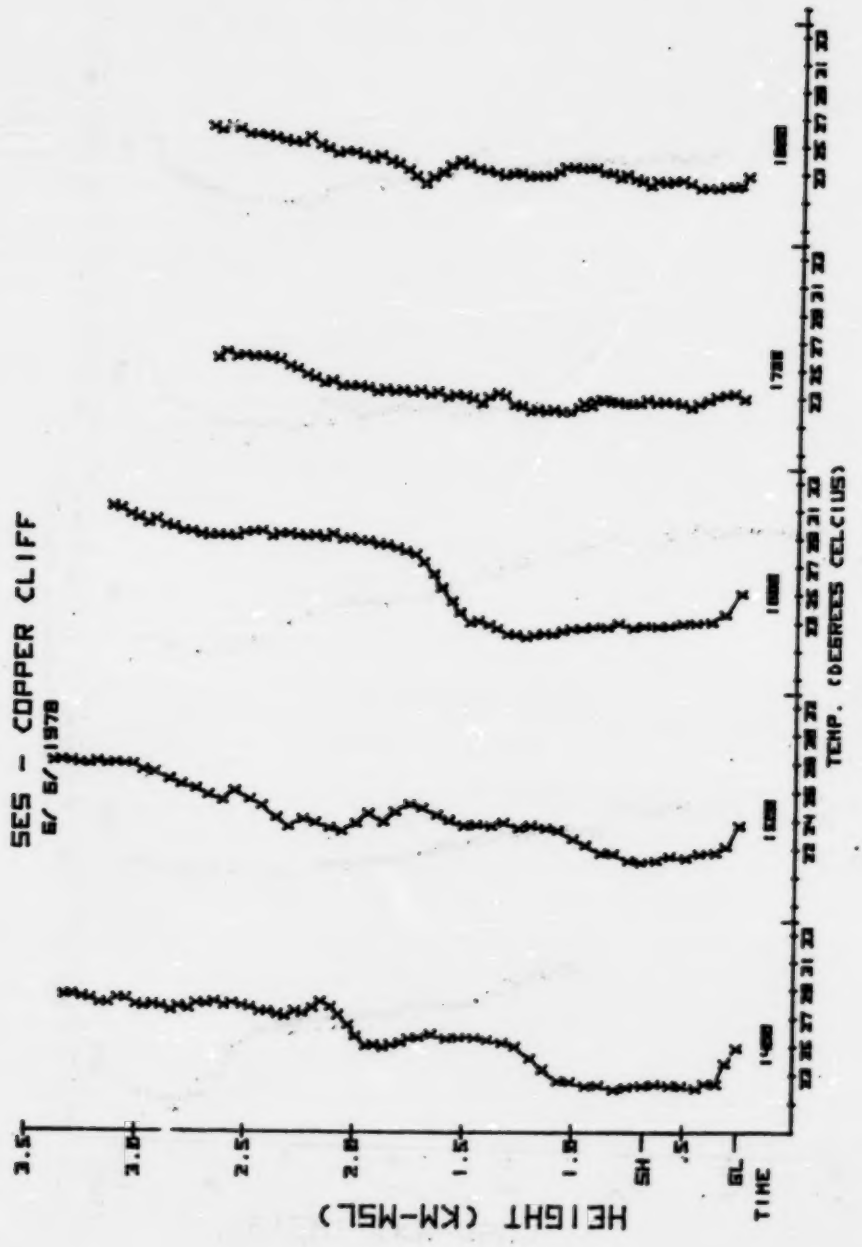

SES - COPPER CLIFF
25/6/1978
1468
DALR
TEMP. (DEGREES CELCIUS)
WIND DIRECTION (DEGREES)
WIND SPEED (M/S)
HEIGHT (KM-MSL)
TS
HS
BL

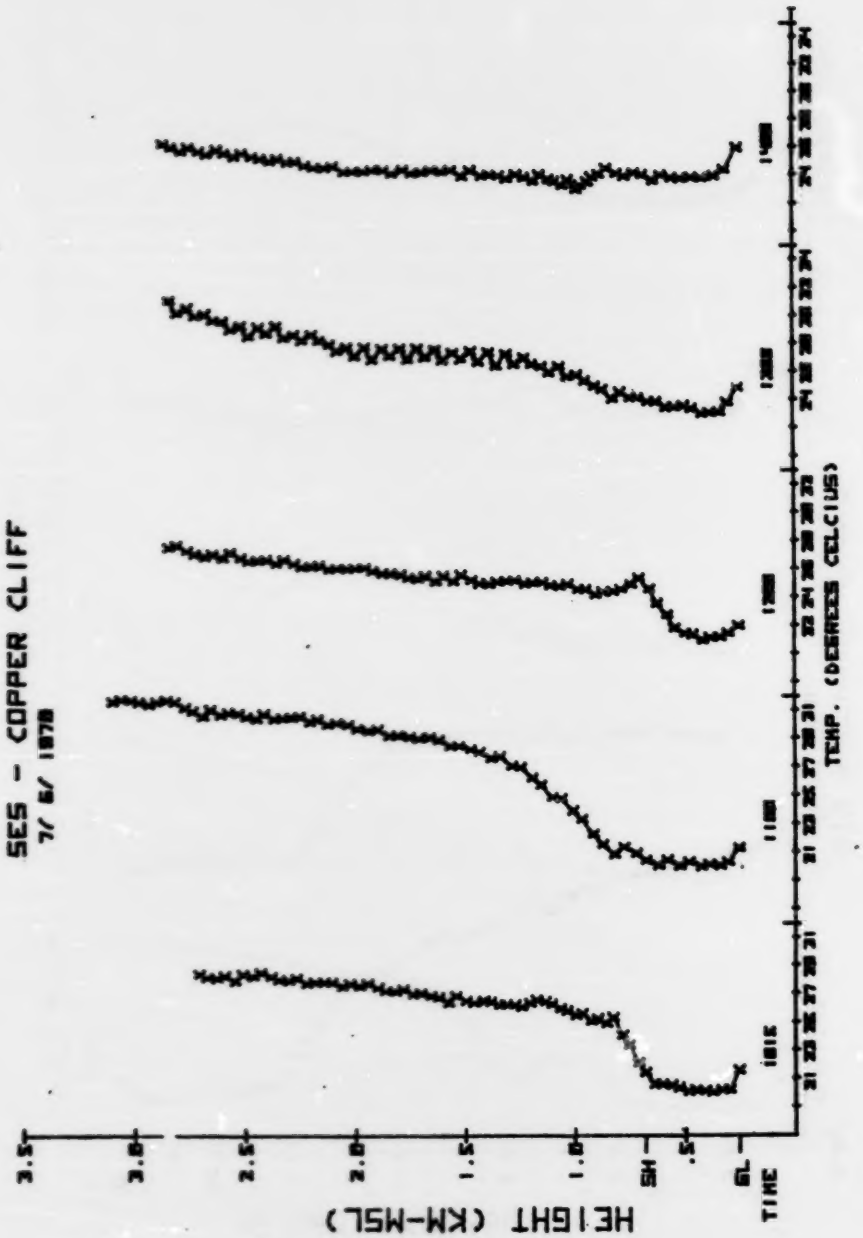
SES - COPPER CLIFF
27/ 6/ 1978
900
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
SH
.5
GL
DALR
2 4 6 8 10 12 14 16 18 20
WIND SPEED (M/S)
180 240 300 360 60 120 180
WIND DIRECTION (DEGREES)
15 19 23 27 31 35 39 43 47
TEMP. (DEGREES CELCIUS)

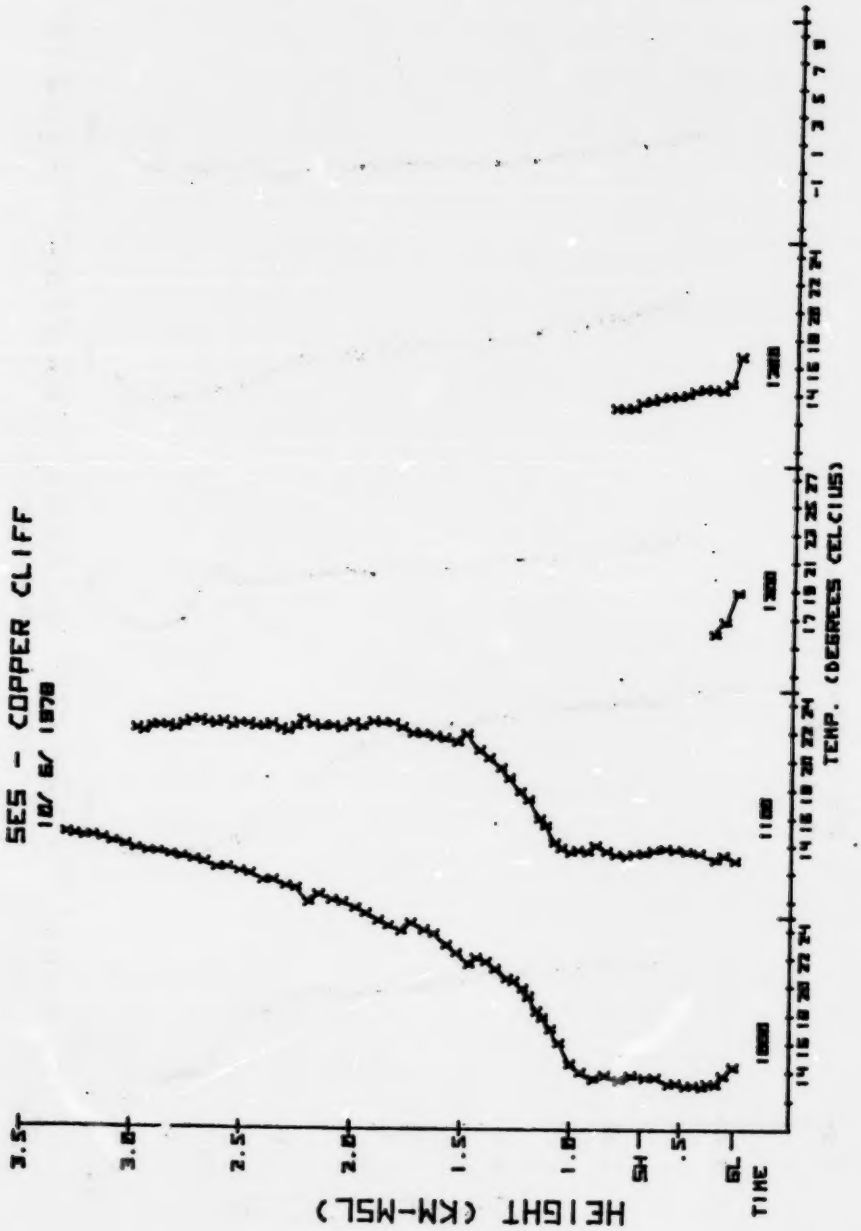

SES - COPPER CLIFF
27/ 6/ 1978
1330
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.5
SH
GL
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
TEMP. (DEGREES CELCIUS)

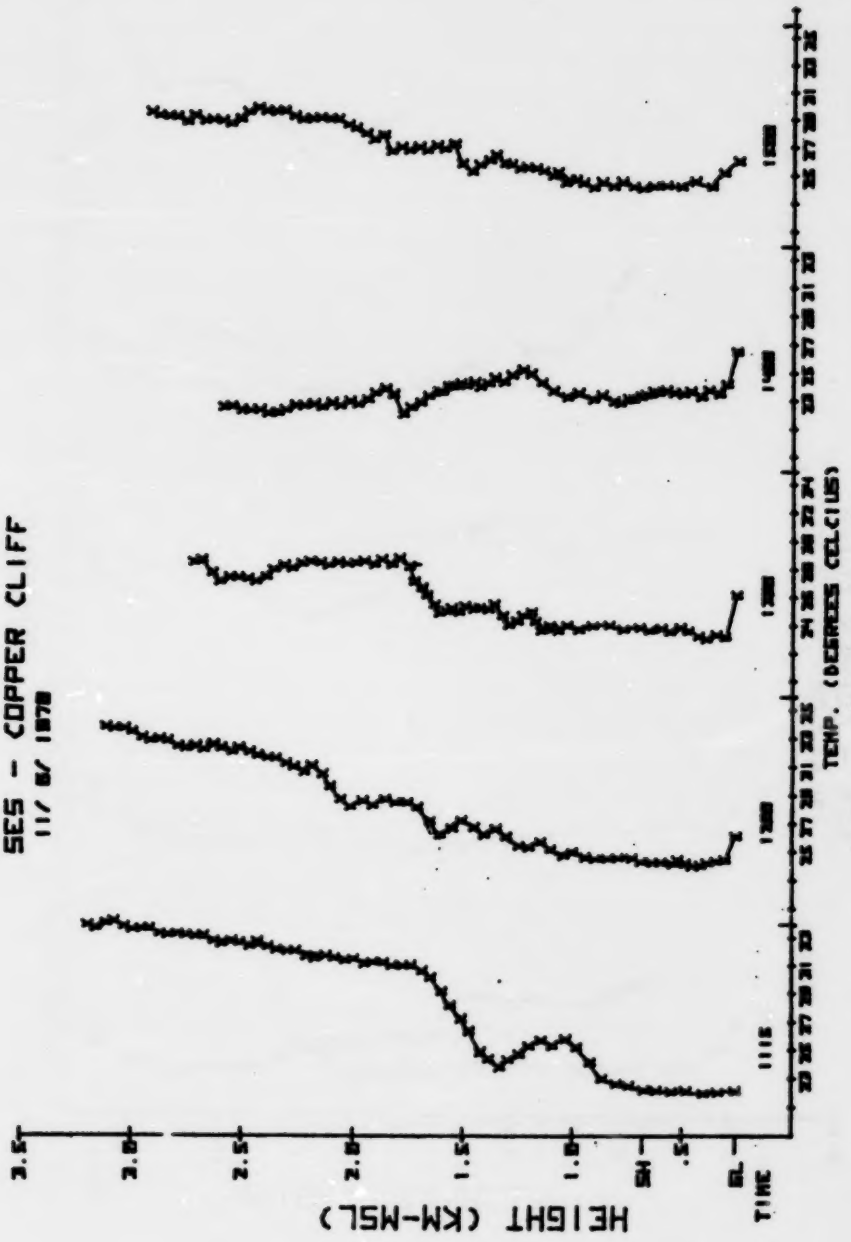
SECTION A.2.2

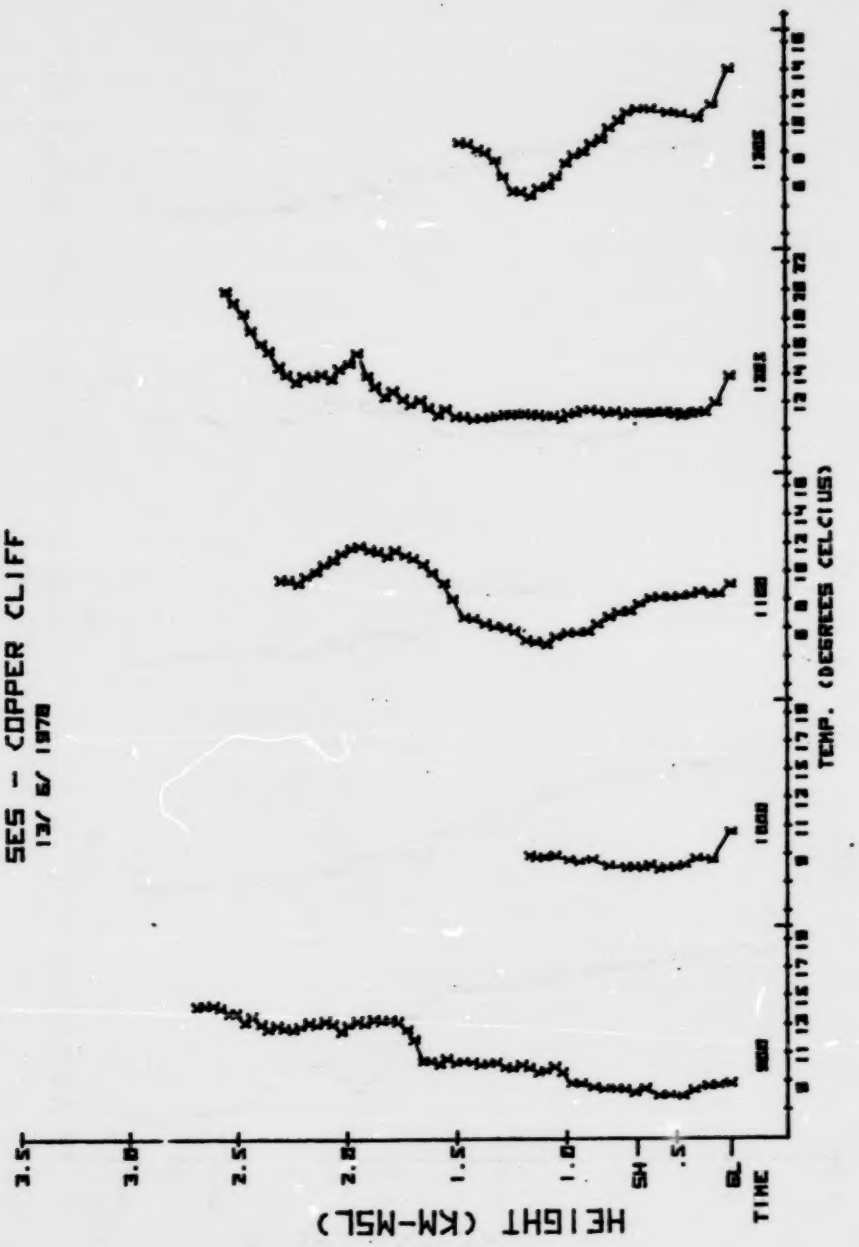

SES - COPPER CLIFF
6/ 6/ 1978
HEIGHT (KM-MSL)
TIME
TEMP. (DEGREES CELCIUS)

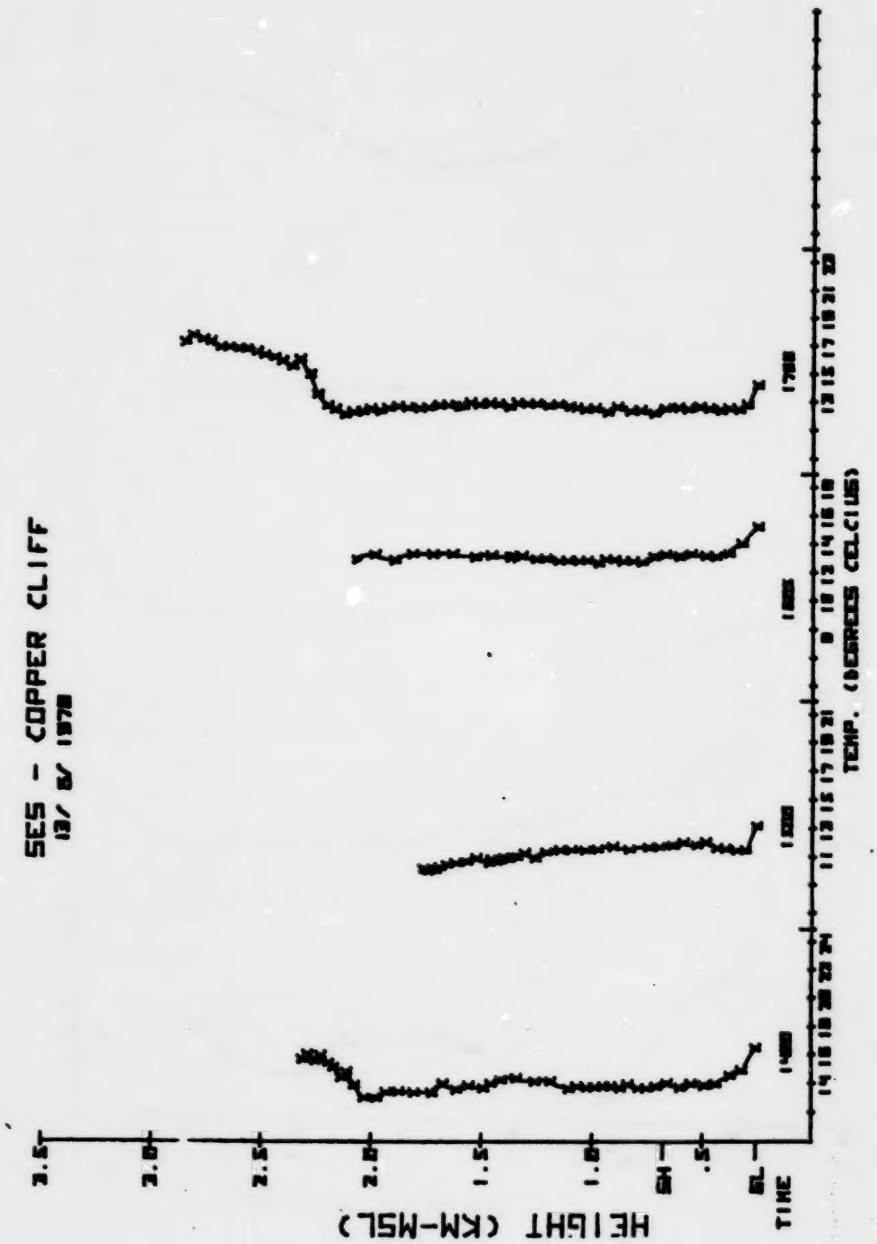

SES - COPPER CLIFF
6/ 6/1978
HEIGHT (KM-MSL)
TEMP. (DEGREES CELCIUS)
TIME
SH
GL

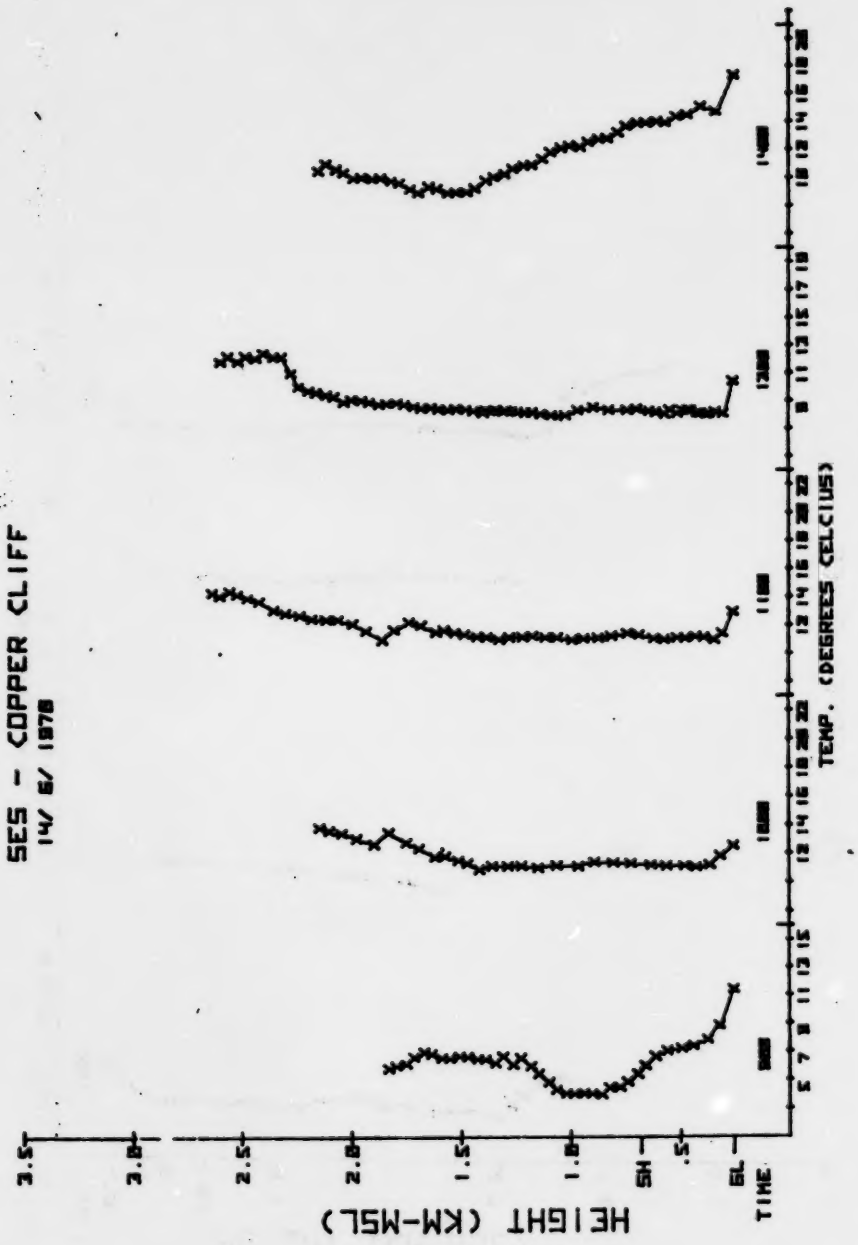

SES - COPPER CLIFF
7/ 6/ 1978
HEIGHT (KM-MSL)
TIME
TEMP. (DEGREES CELCIUS)

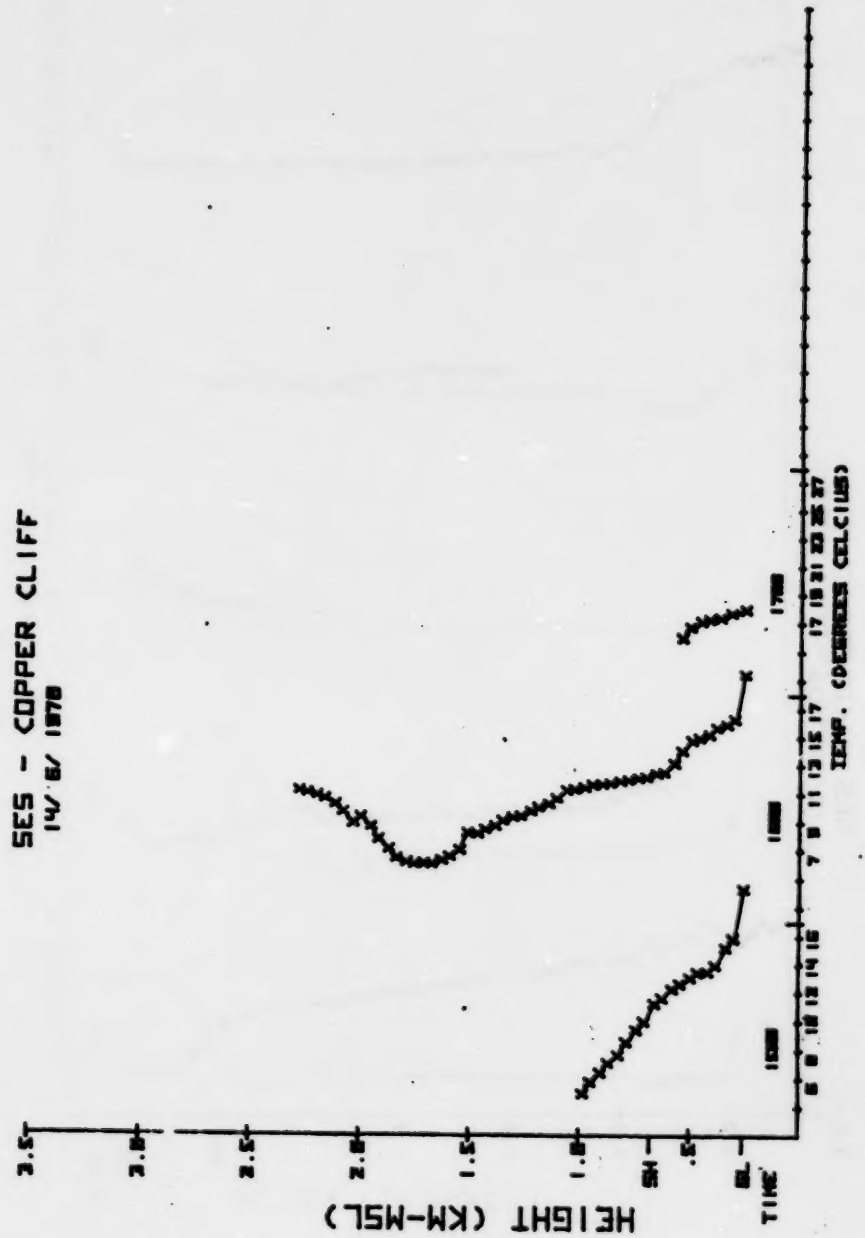

SES - COPPER CLIFF
10/ 6/ 1978
HEIGHT (KM-MSL)
TIME
TEMP. (DEGREES CELCIUS)

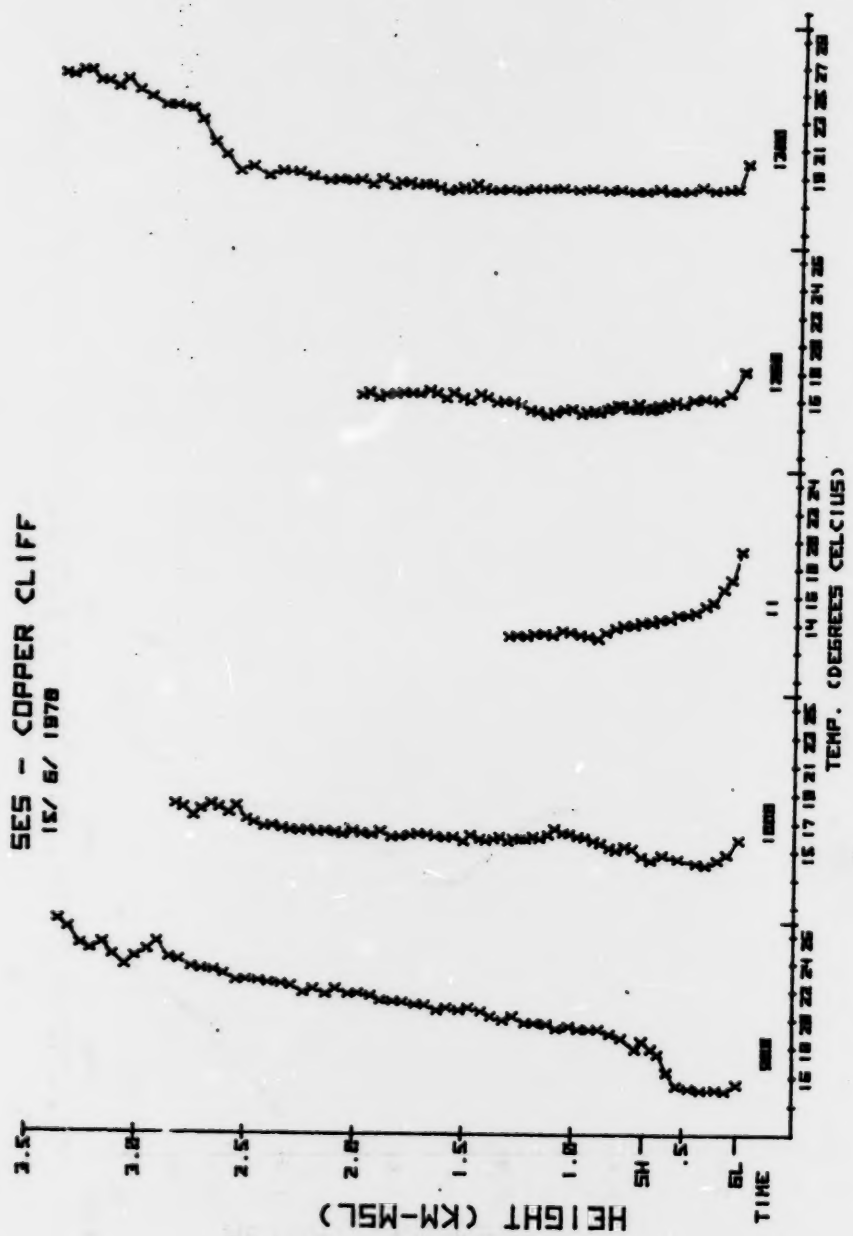

SES - COPPER CLIFF
11/ 8/ 1978
HEIGHT (KM-MSL)
TEMP. (DEGREES CELCIUS)
TIME
SL
MS
.5
1.0
1.5
2.0
2.5
3.0
3.5
1115
1200
1300
1400
1500

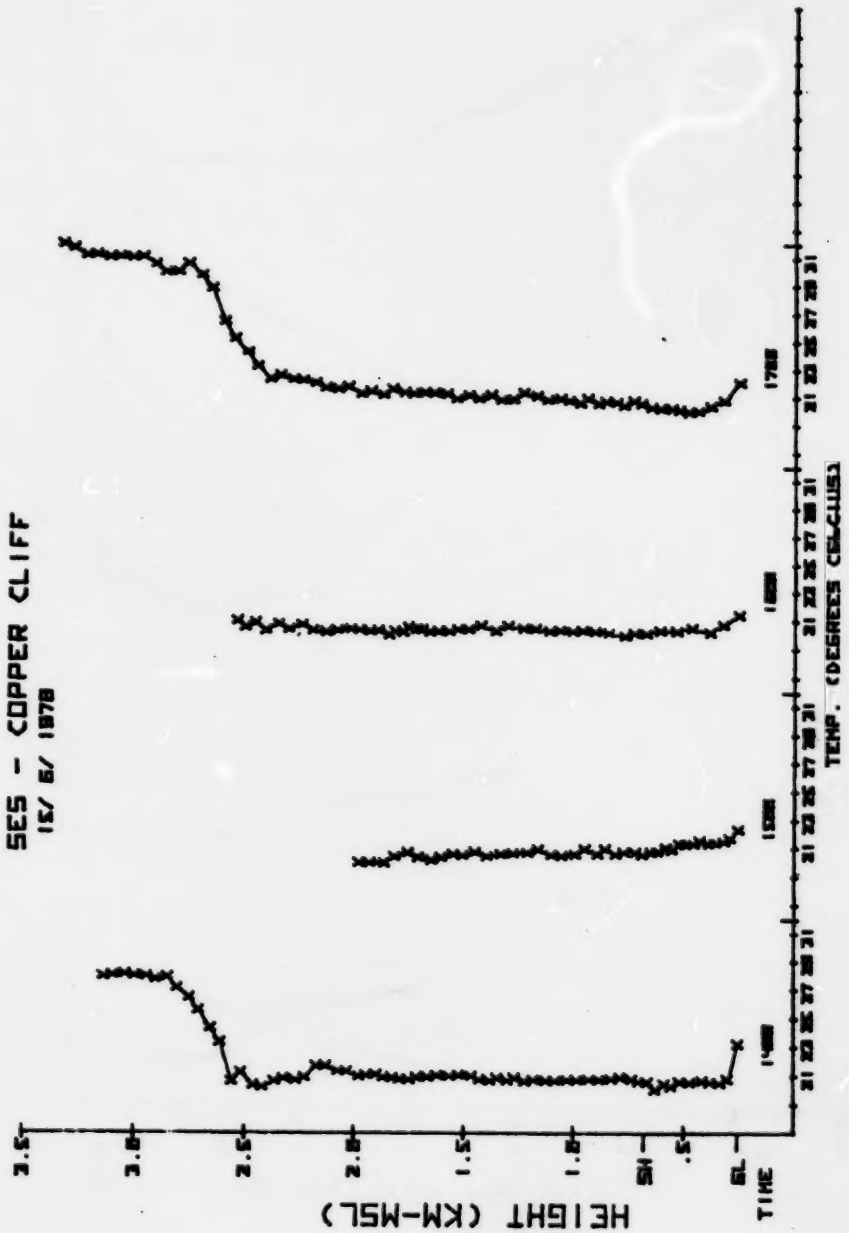

SES - COPPER CLIFF
13/ 6/ 1978
HEIGHT (KM-MSL)
3.5
3.0
2.5
2.0
1.5
1.0
MS
.5
GL
TIME
TEMP. (DEGREES CELCIUS)

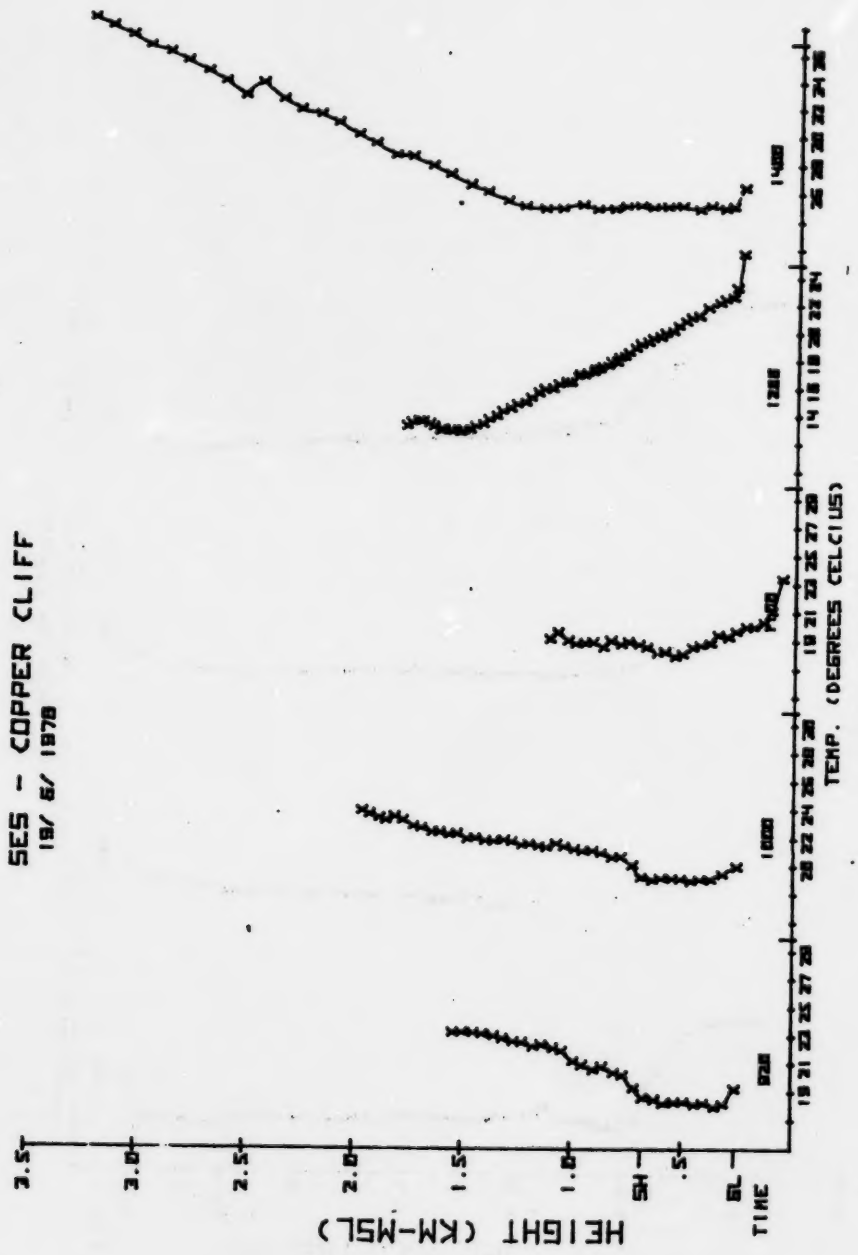

SES - COPPER CLIFF
13/ 8/ 1978
HEIGHT (KM-MSL)
3.5
3.0
2.5
2.0
1.5
1.0
.5
SH
SL
TIME
TEMP. (DEGREES CELCIUS)

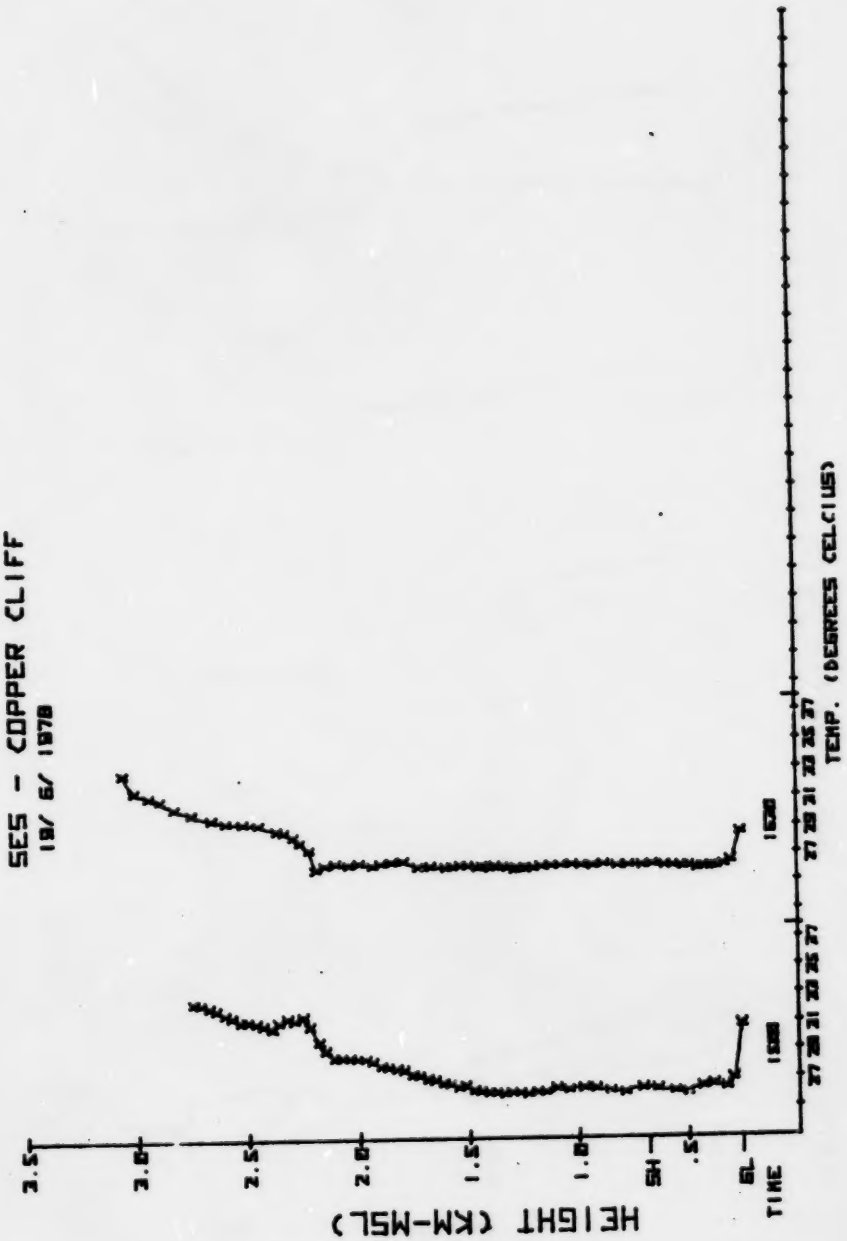

SES - COPPER CLIFF
14/ 6/ 1978
HEIGHT (KM-MSL)
TIME
TEMP. (DEGREES CELCIUS)

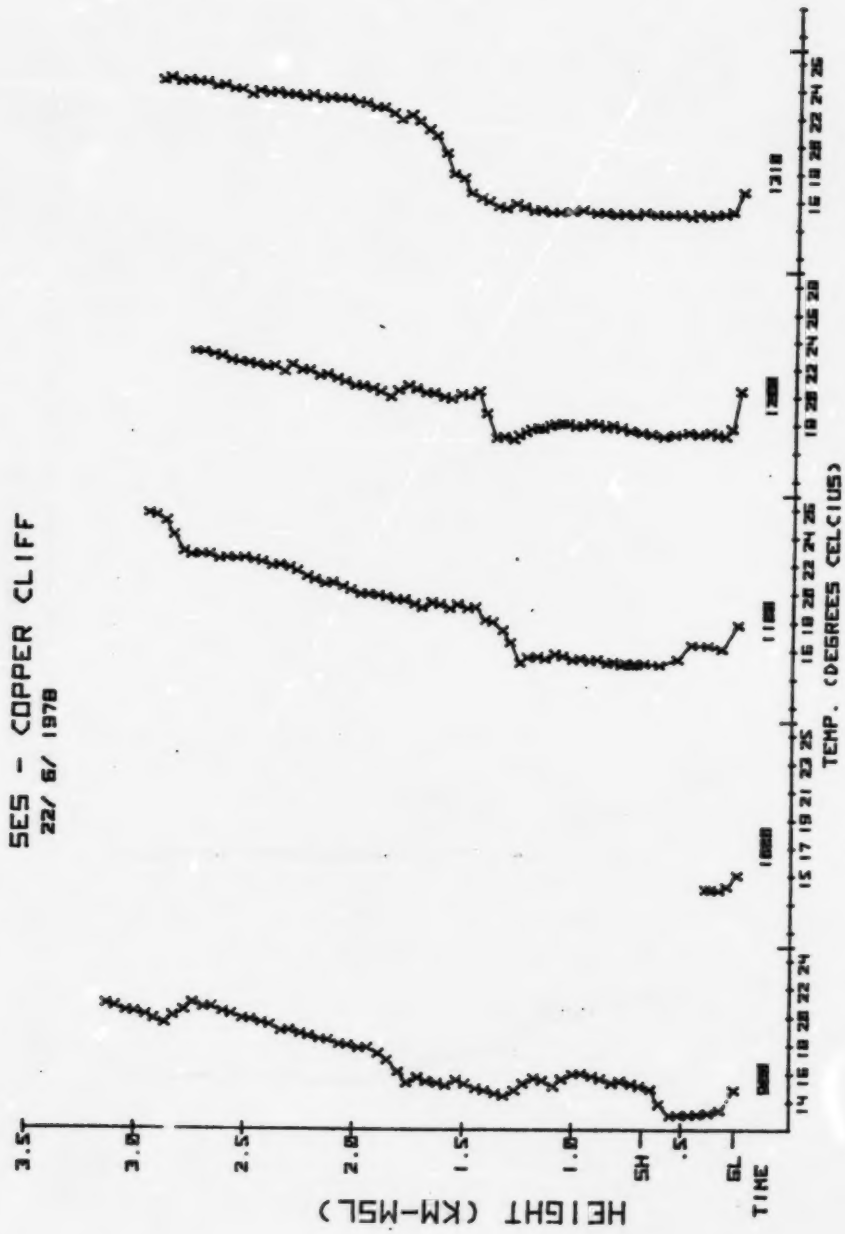

SES - COPPER CLIFF
14/ 6/ 1978
HEIGHT (KM-MSL)
TIME
TEMP. (DEGREES CELCIUS)

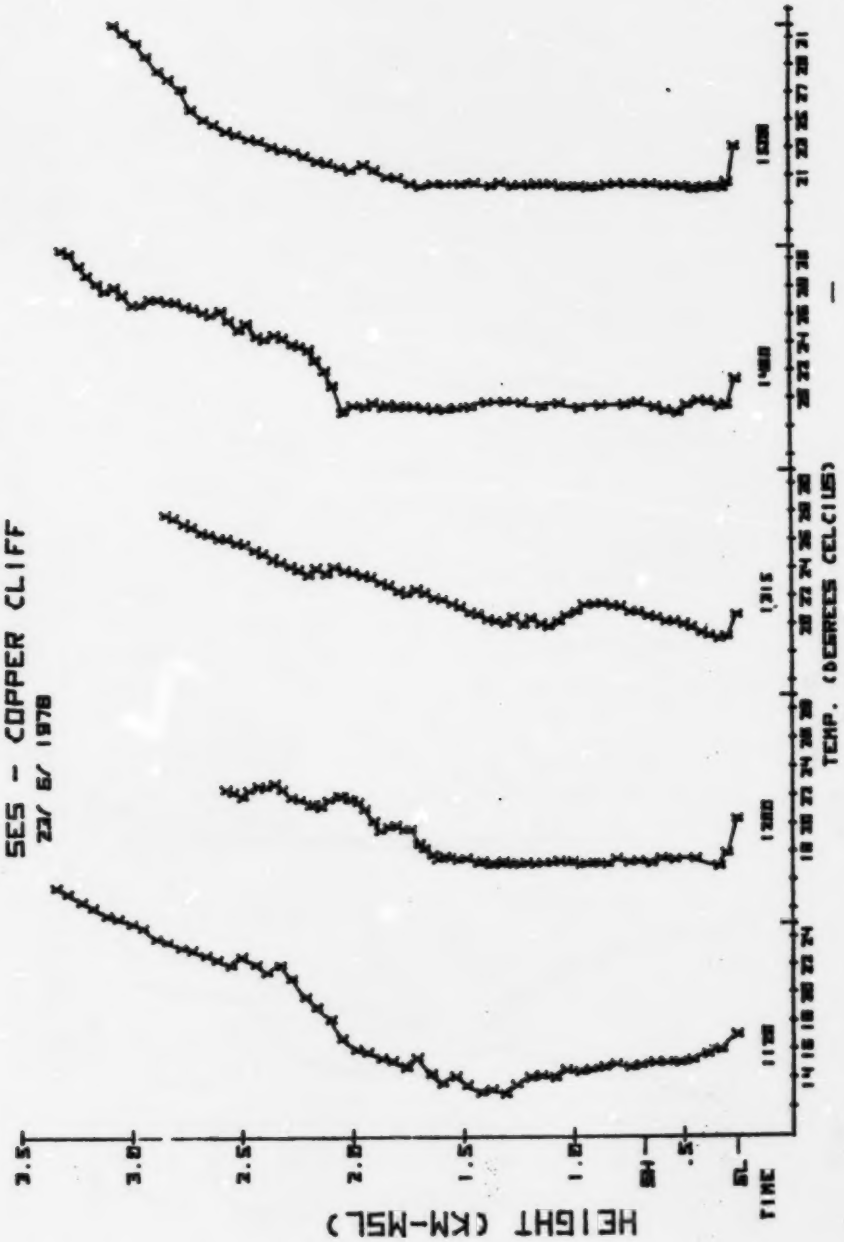

SES - COPPER CLIFF
15/ 6/ 1978
HEIGHT (KM-MSL)
TEMP. (DEGREES CELCIUS)
TIME
3.5
3.0
2.5
2.0
1.5
1.0
.5
HS
GL

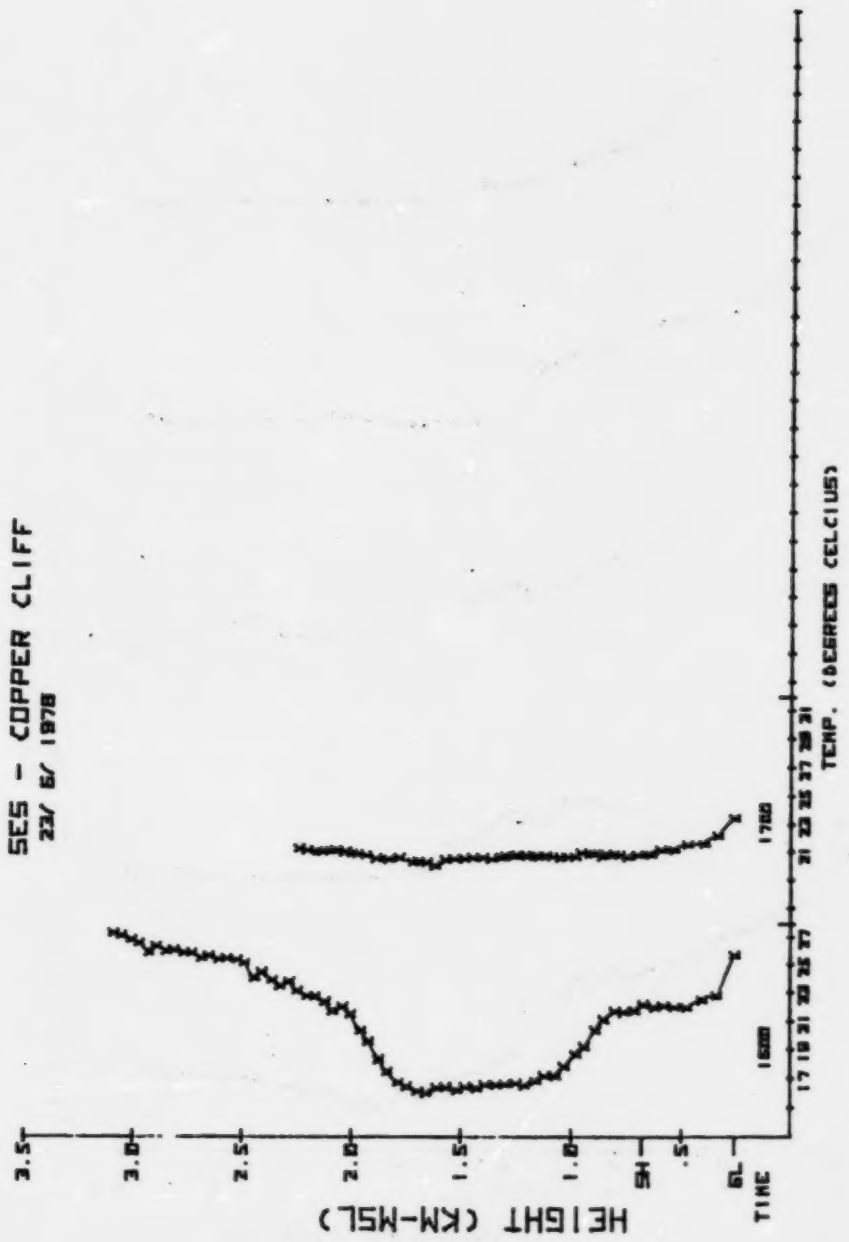

SES - COPPER CLIFF
15/ 6/ 1978
HEIGHT (KM-MSL)
TIME
TEMP. (DEGREES CELCIUS)

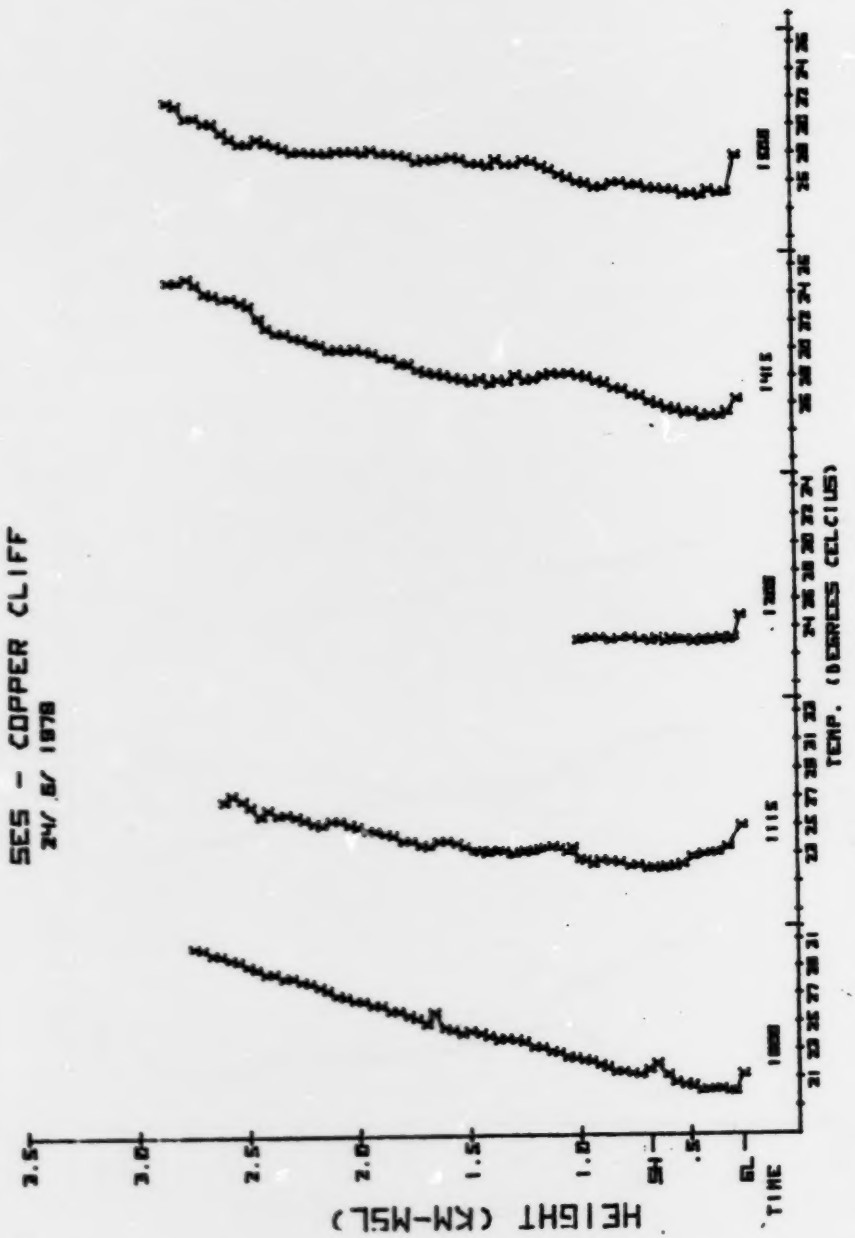

SES - COPPER CLIFF
19/ 6/ 1978
HEIGHT (KM-MSL)
TIME
TEMP. (DEGREES CELCIUS)

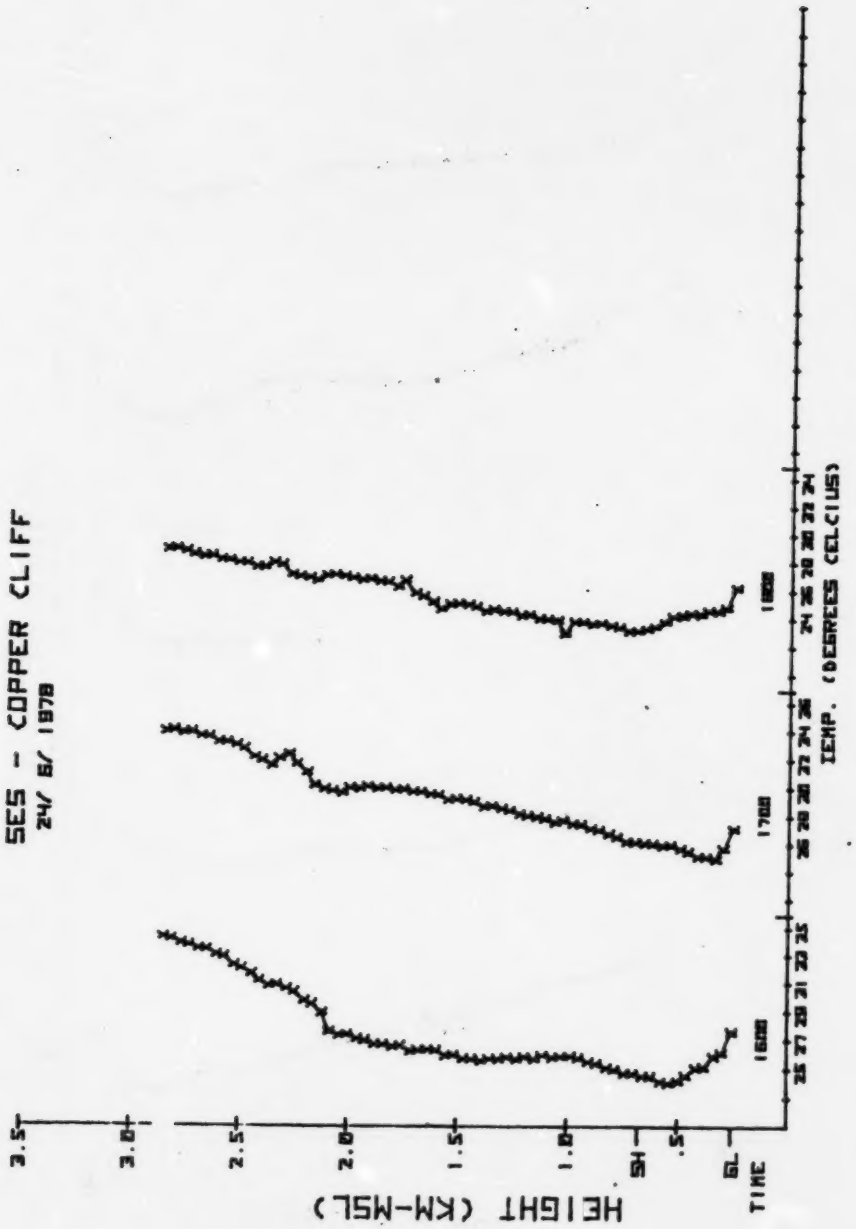

SES - COPPER CLIFF
19/ 6/ 1978
HEIGHT (KM-MSL)
TIME
TEMP. (DEGREES CELCIUS)

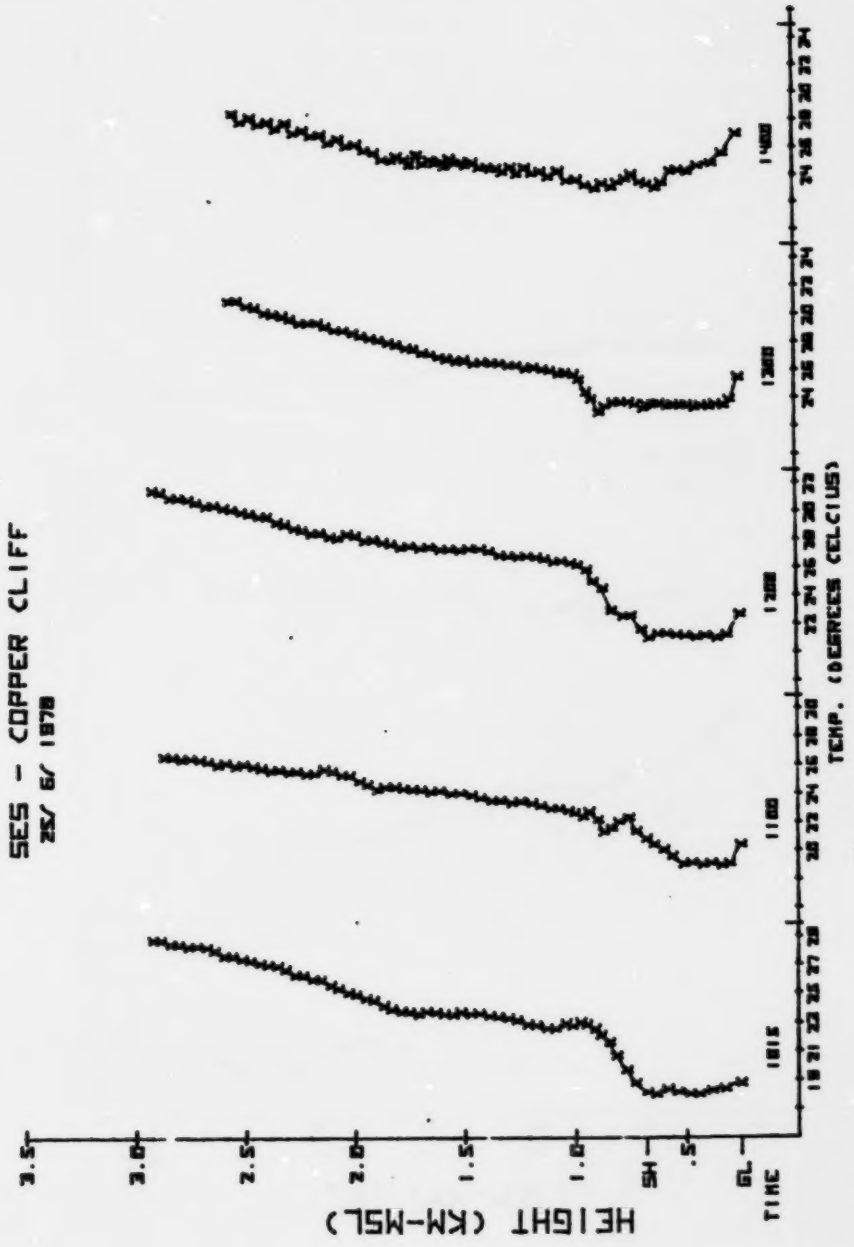

SES - COPPER CLIFF
22/ 6/ 1978
HEIGHT (KM-MSL)
TIME
TEMP. (DEGREES CELCIUS)

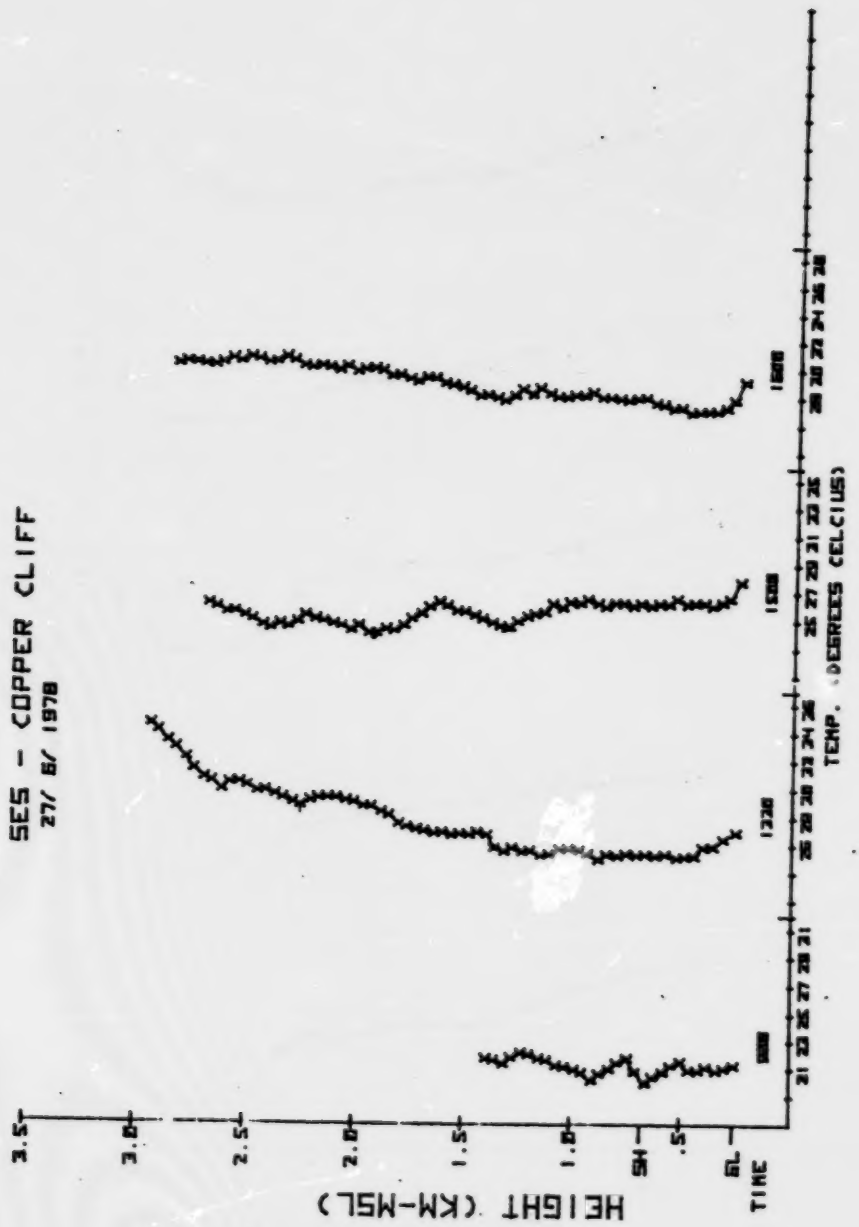

SES - COPPER CLIFF
23/ 8/ 1978
HEIGHT (KM-MSL)
TEMP. (DEGREES CELCIUS)
TIME


SES - COPPER CLIFF
23/ 6/ 1978
HEIGHT (KM-MSL)
3.5
3.0
2.5
2.0
1.5
1.0
MS
.5
GL
TIME
1600
1700
TEMP. (DEGREES CELCIUS)

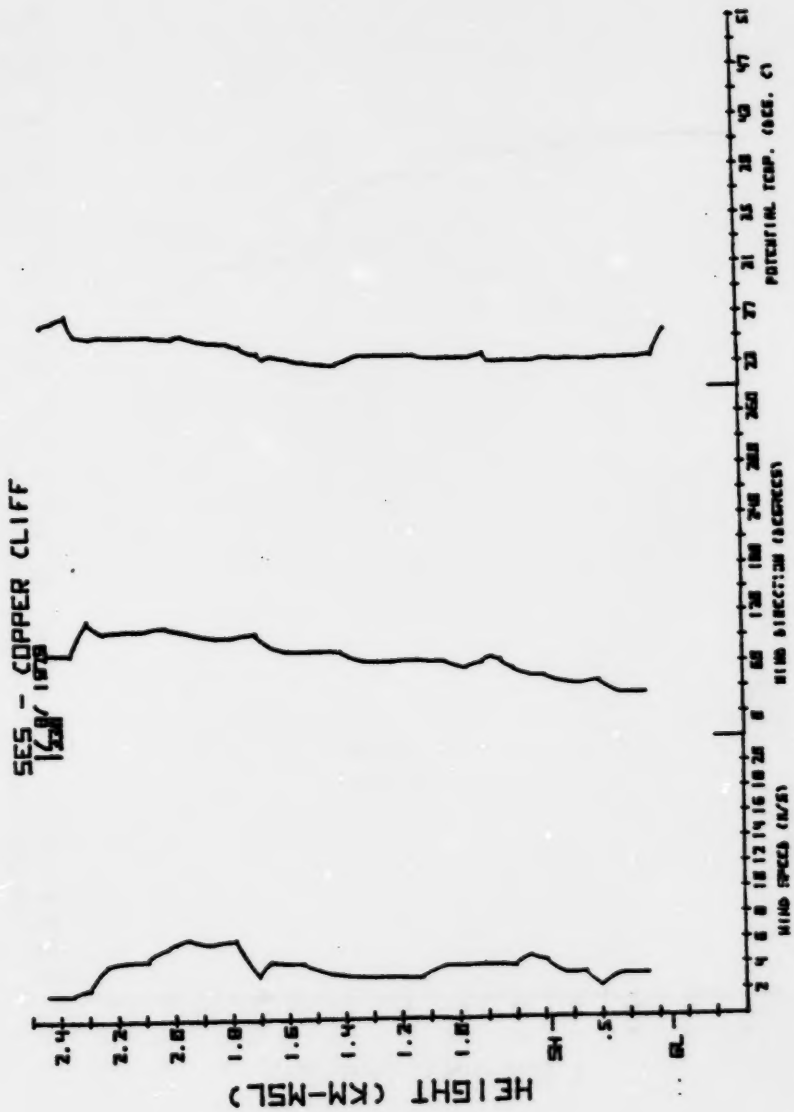

SES - COPPER CLIFF
24/ 8/ 1978
HEIGHT (KM-MSL)
TIME
TEMP. (DEGREES CELCIUS)

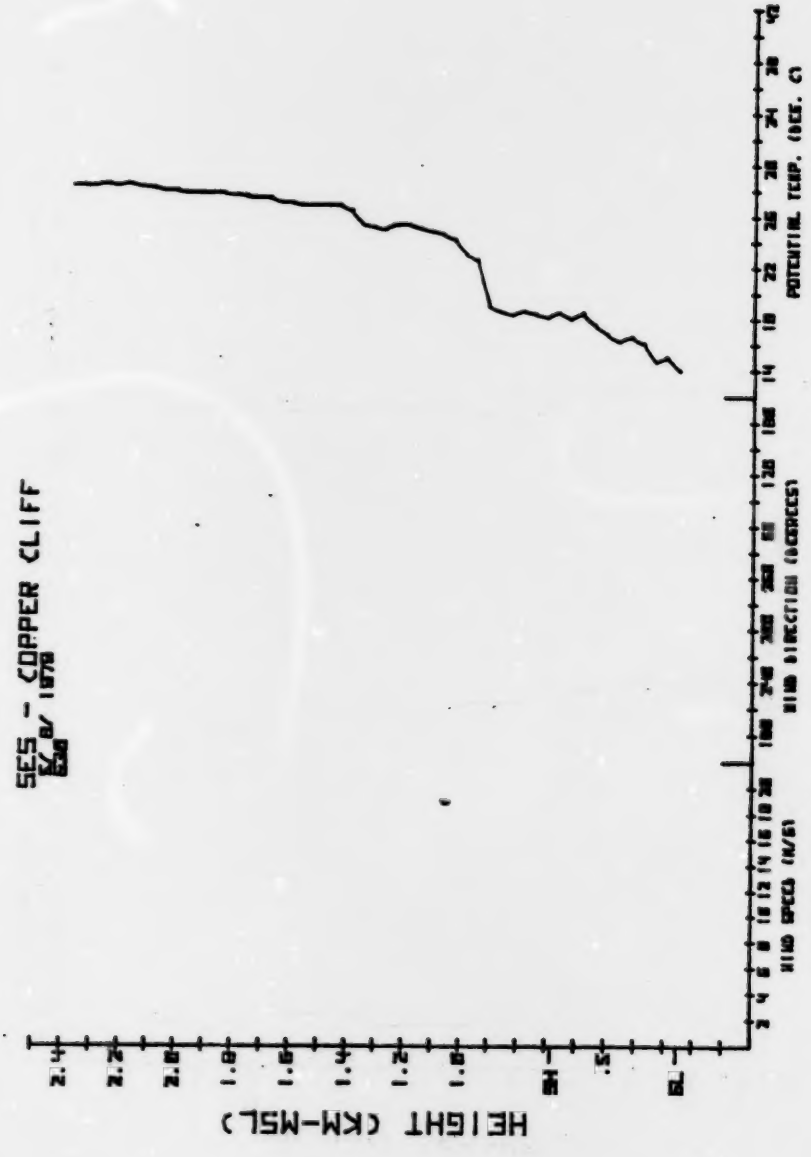

SES - COPPER CLIFF
24/ 8/ 1978
HEIGHT (KM-MSL)
3.5
3.0
2.5
2.0
1.5
1.0
.5
SH
GL
TIME
1600
1700
1800
TEMP. (DEGREES CELCIUS)

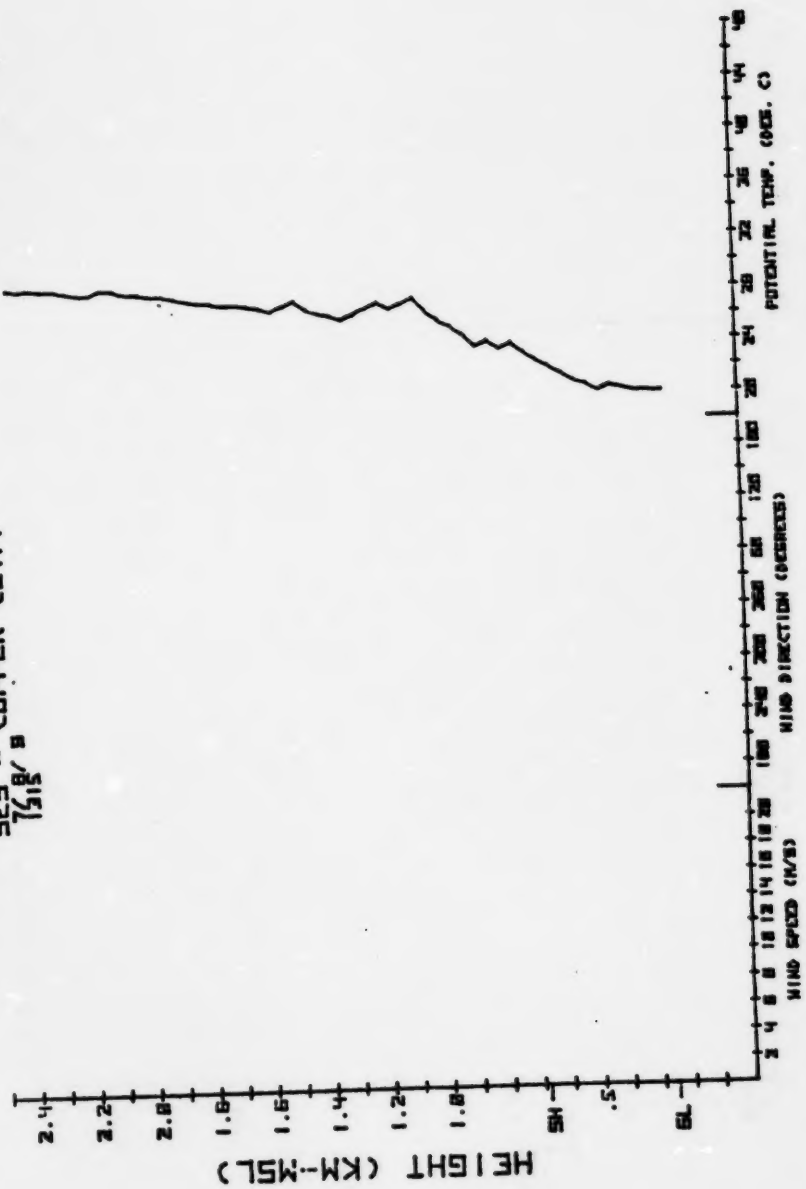

SES - COPPER CLIFF
25/ 6/ 1978
HEIGHT (KM-MSL)
3.5
3.0
2.5
2.0
1.5
1.0
MS
.5
GL
TIME
1815
1900
1945
2030
2115
TEMP. (DEGREES CELCIUS)

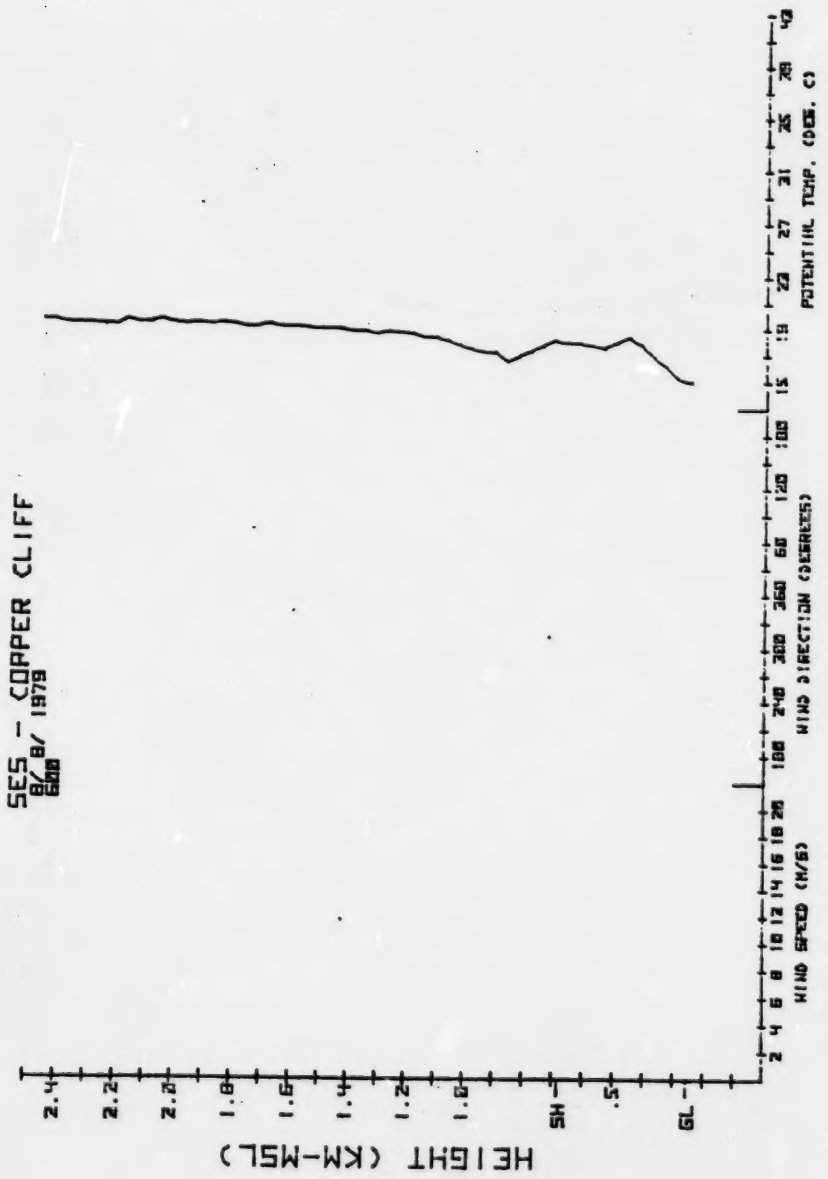

SES - COPPER CLIFF
27/ 8/ 1978
HEIGHT (KM-MSL)
TEMP. DEGREES CELCIUS
TIME
3.5
3.0
2.5
2.0
1.5
1.0
MS
.5
GL
0000
1200
1500
1800

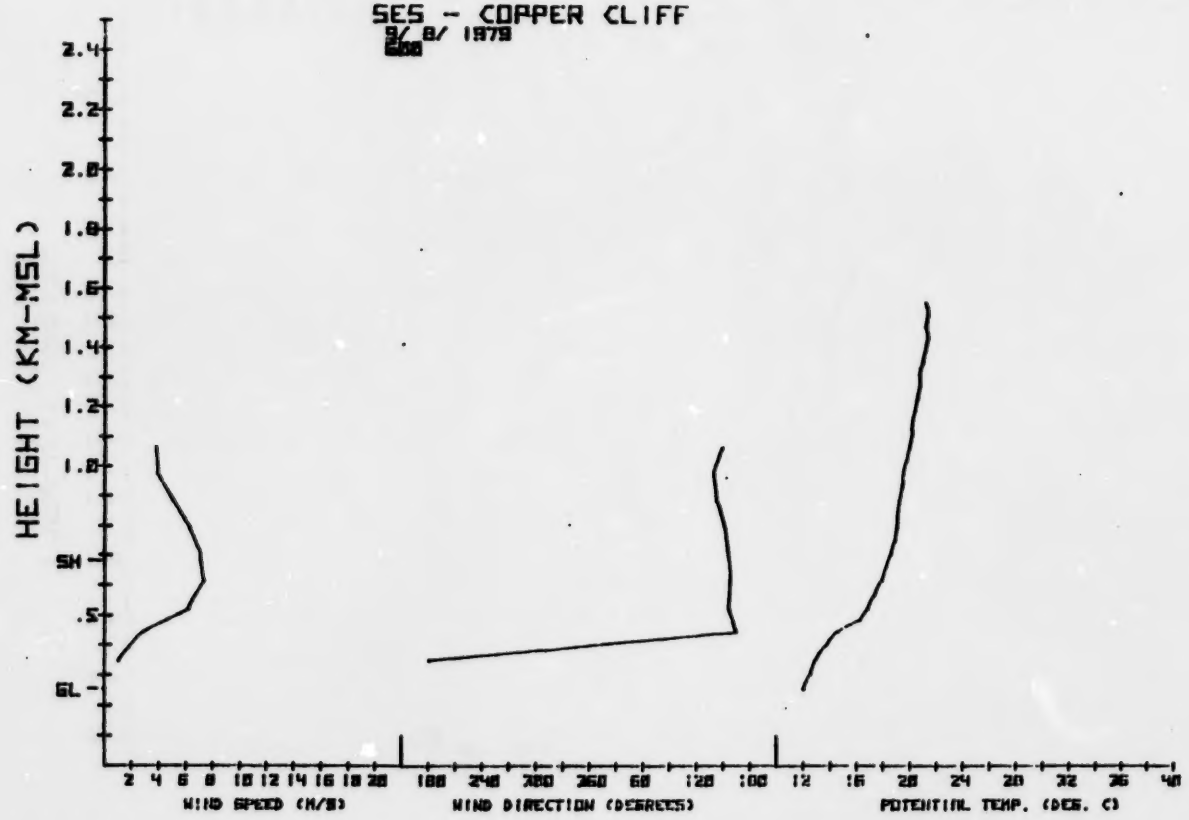
SECTION A.2.3

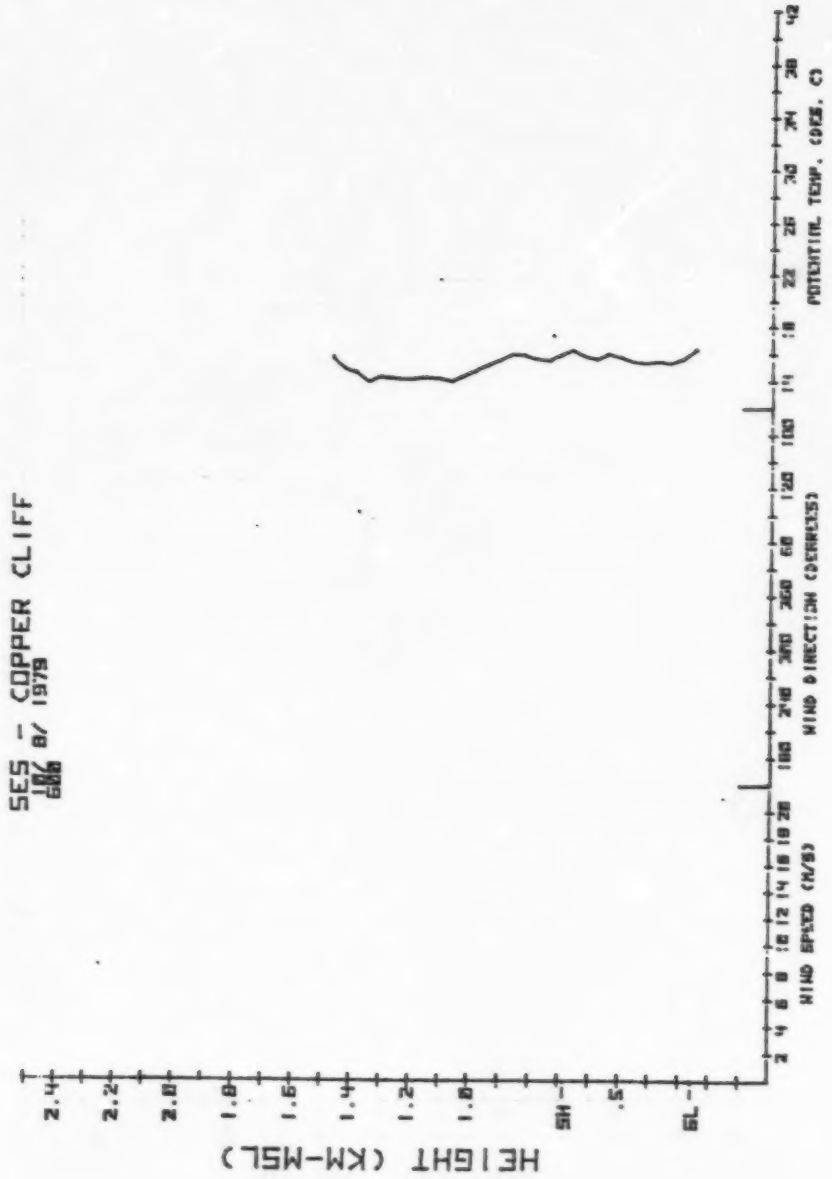

SES - COPPER CLIFF
HEIGHT (KM-MSL)
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG. C)

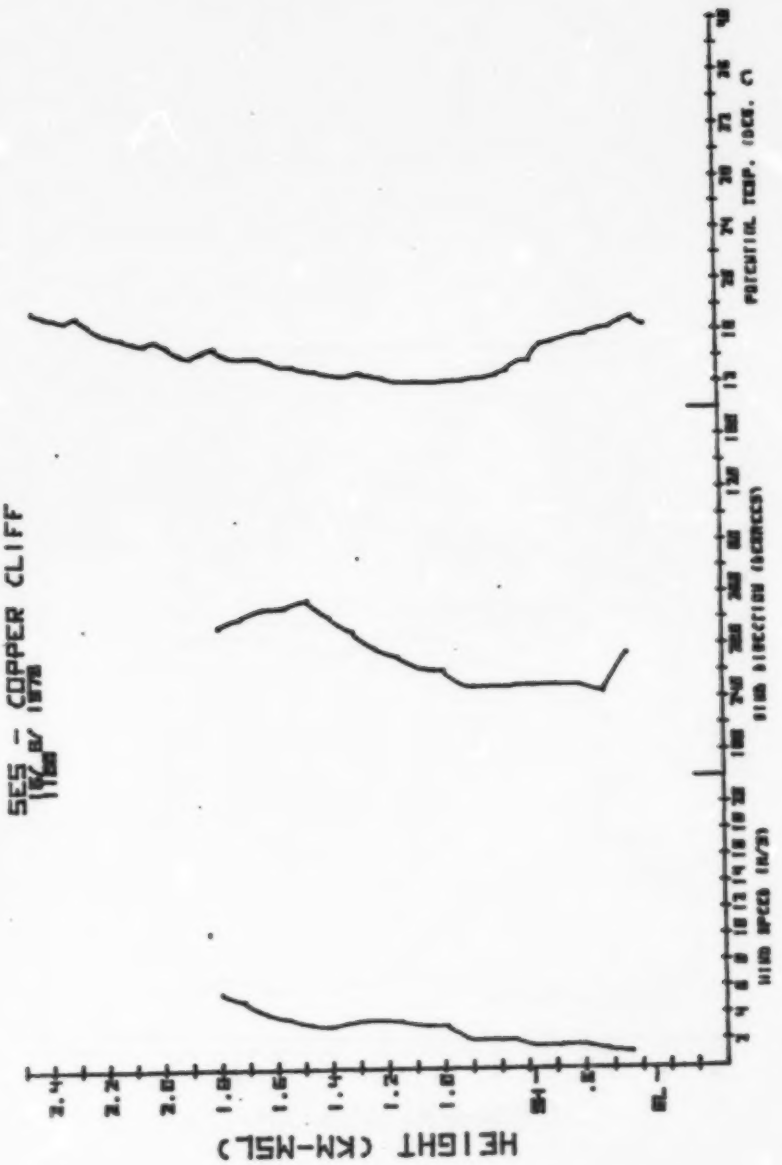

SES - COPPER CLIFF
HEIGHT (KM-MSL)

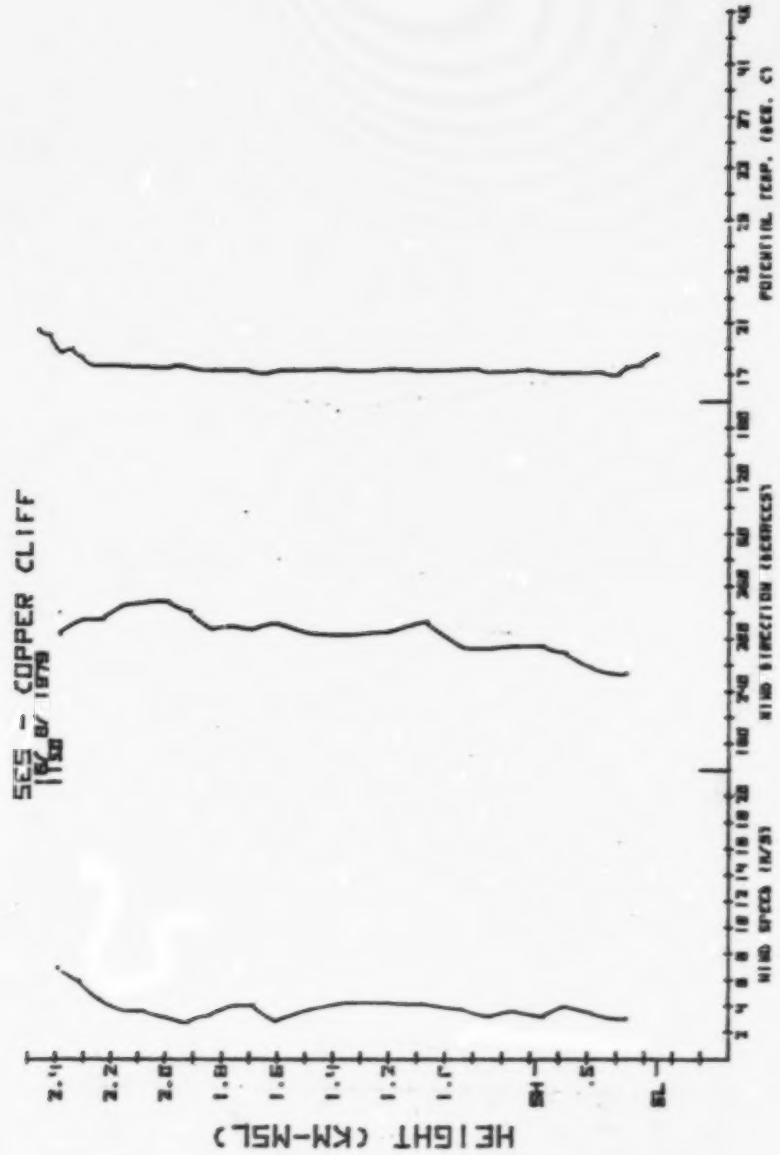

SES - COPPER CLIFF
HEIGHT (KM--MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.5
HS
GL
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG. C)

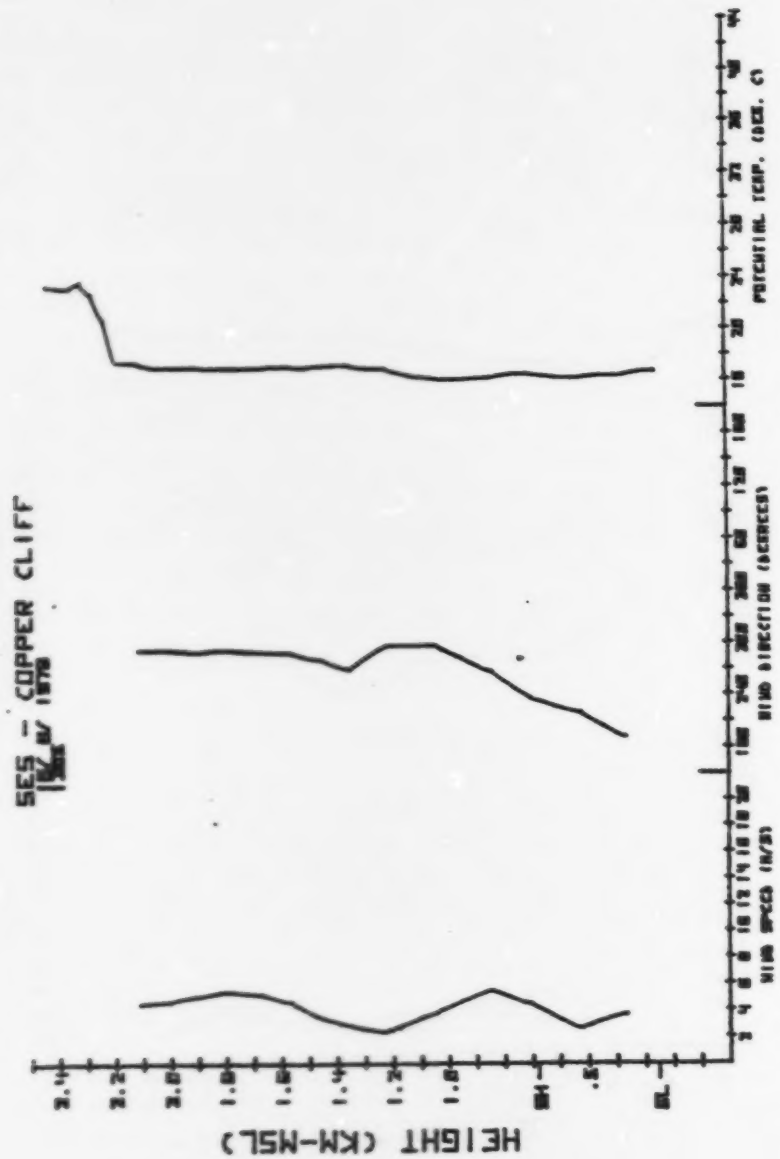

SES - COPPER CLIFF
8/8/ 1979
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.5
SH
GL
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG. C)

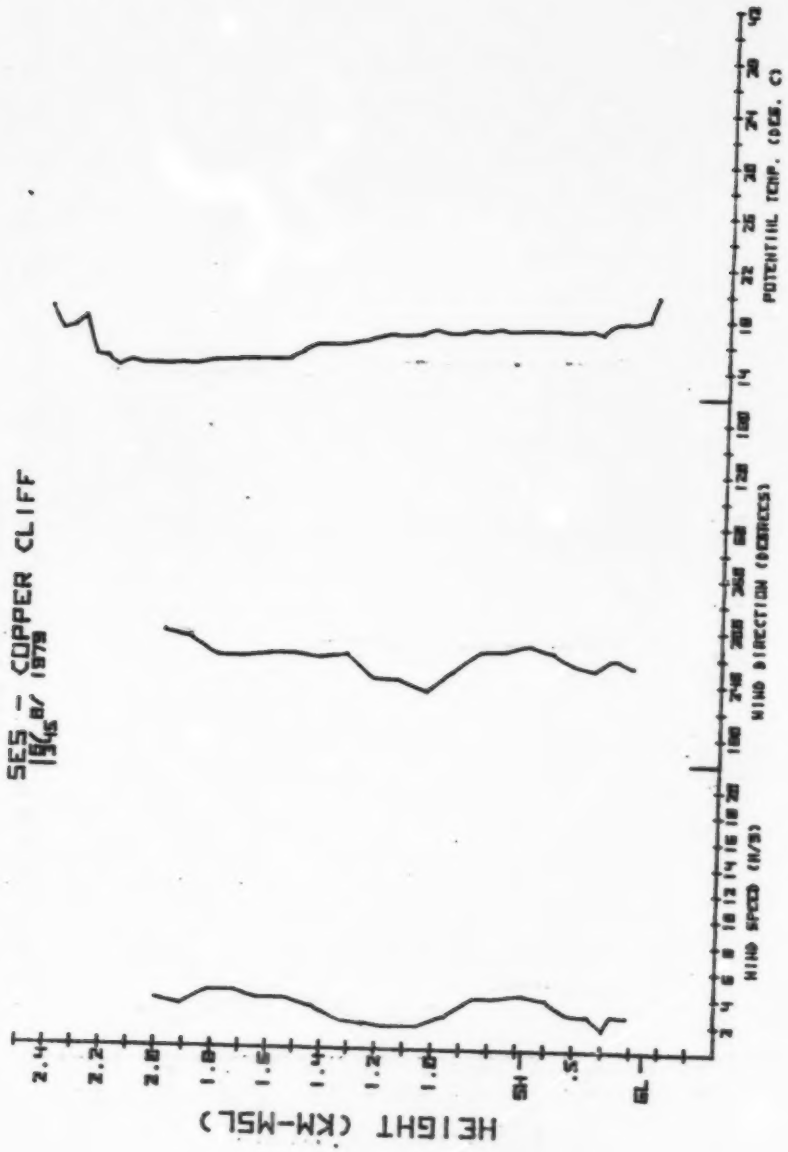

SES - COPPER CLIFF
9/ 8/ 1979
2000
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
SH
.5
GL
2 4 6 8 10 12 14 16 18 20
WIND SPEED (M/S)
180 240 300 360 60 120 180
WIND DIRECTION (DEGREES)
12 16 20 24 28 32 36 40
POTENTIAL TEMP. (DEG. C)

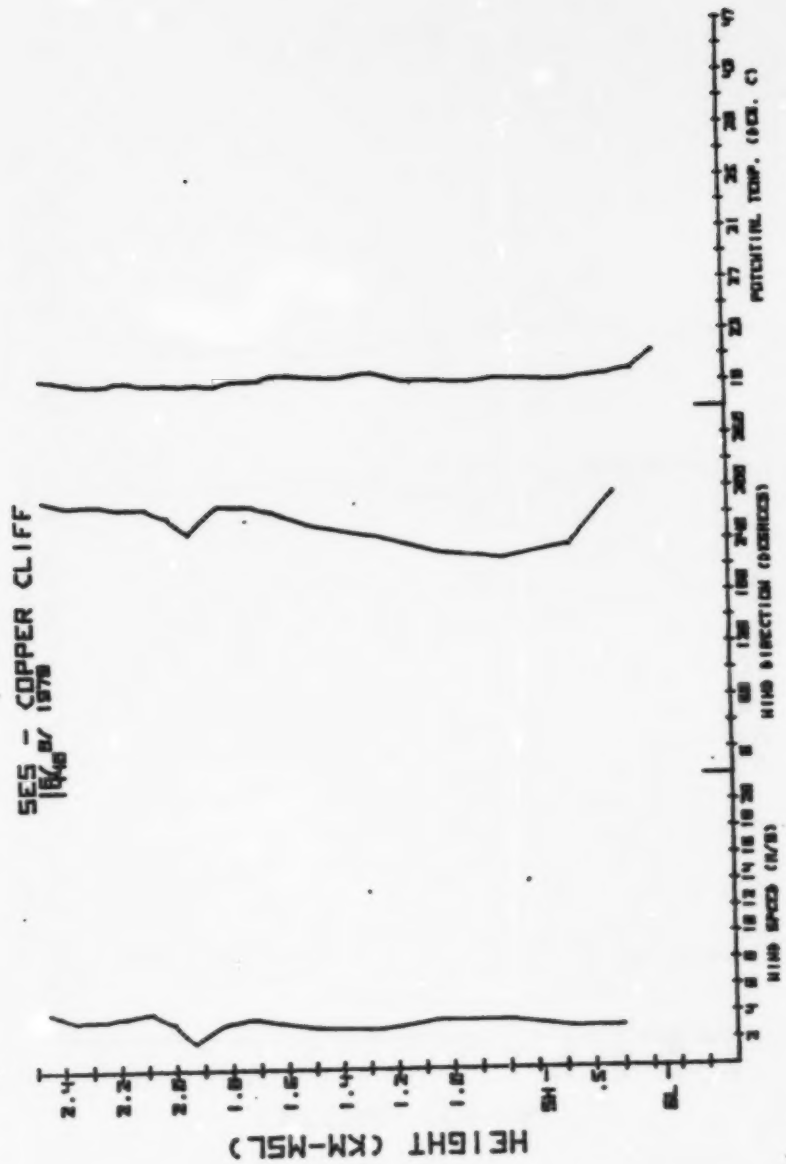

SES - COPPER CLIFF
JUL 8/ 1979
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.5
SH
SL
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG. C)

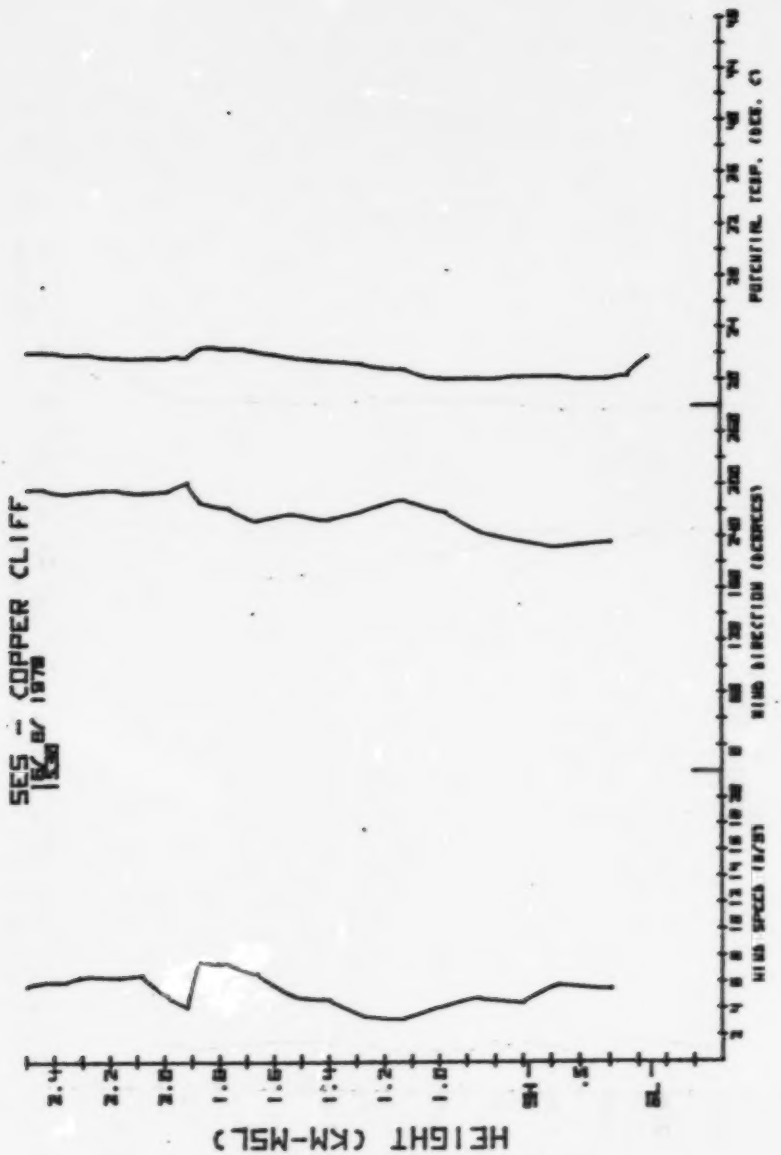

SES - COPPER CLIFF
HEIGHT (KM-MSL)

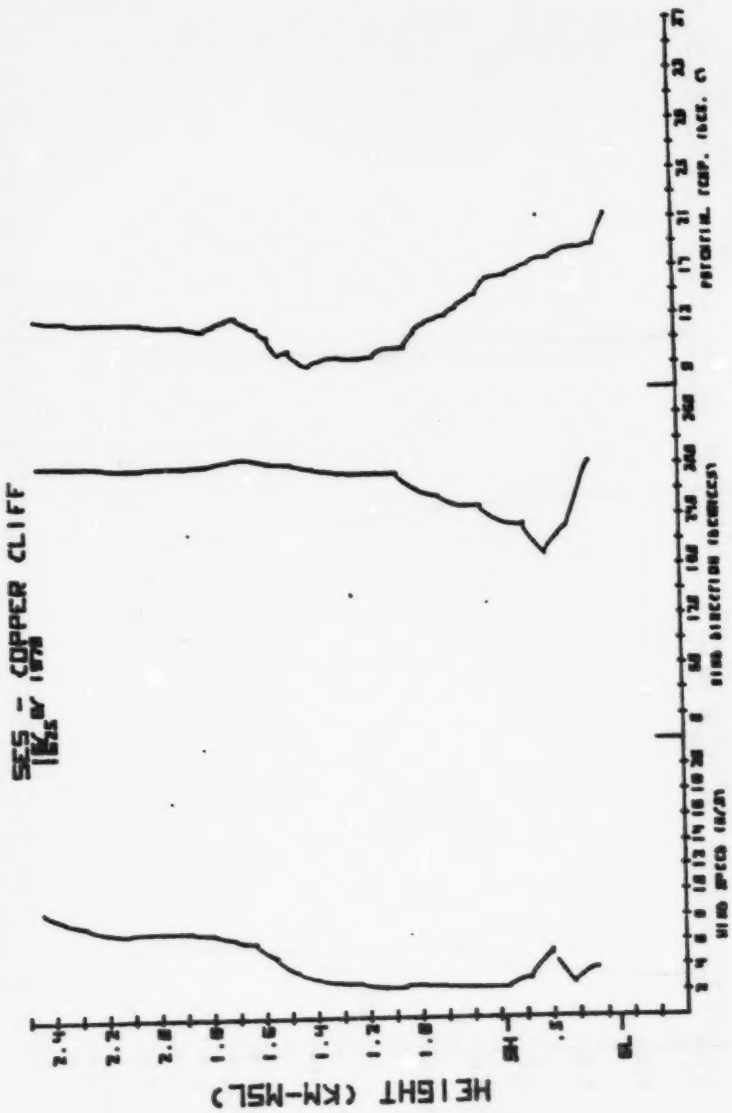

SES - COPPER CLIFF
HEIGHT (KM-MSL)
WIND SPEED (KNOTS)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG. C)

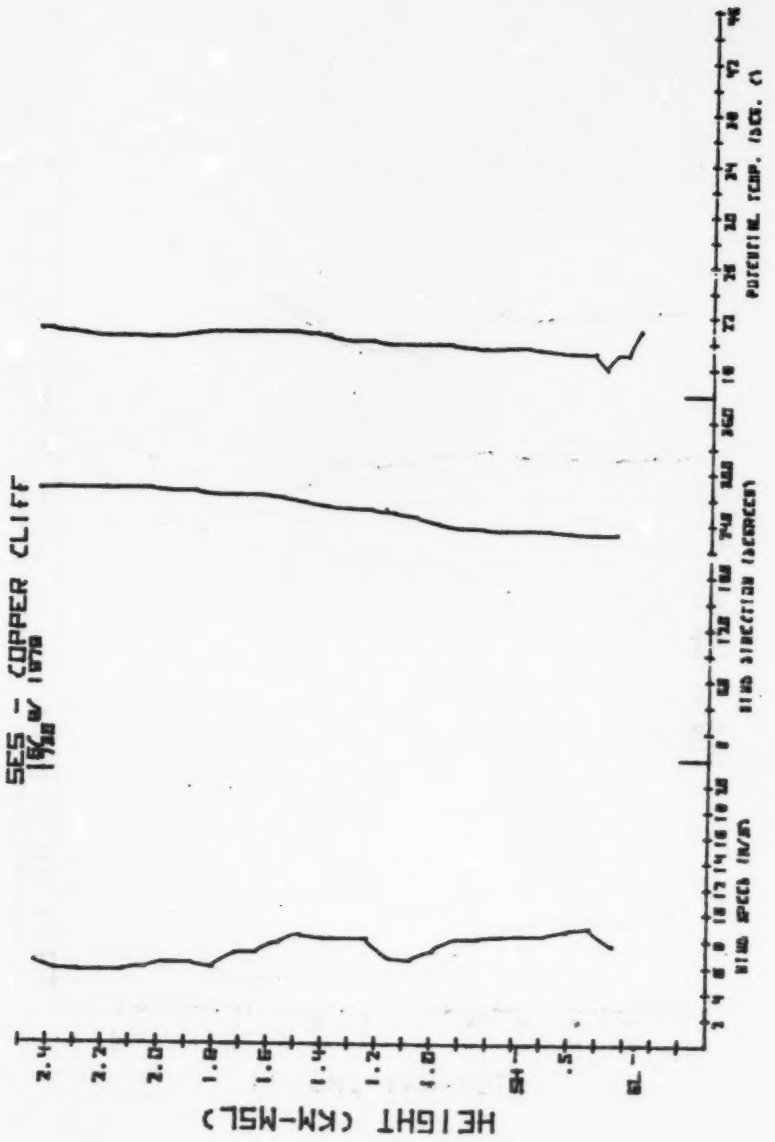

SES - COPPER CLIFF
HEIGHT (KM-MSL)

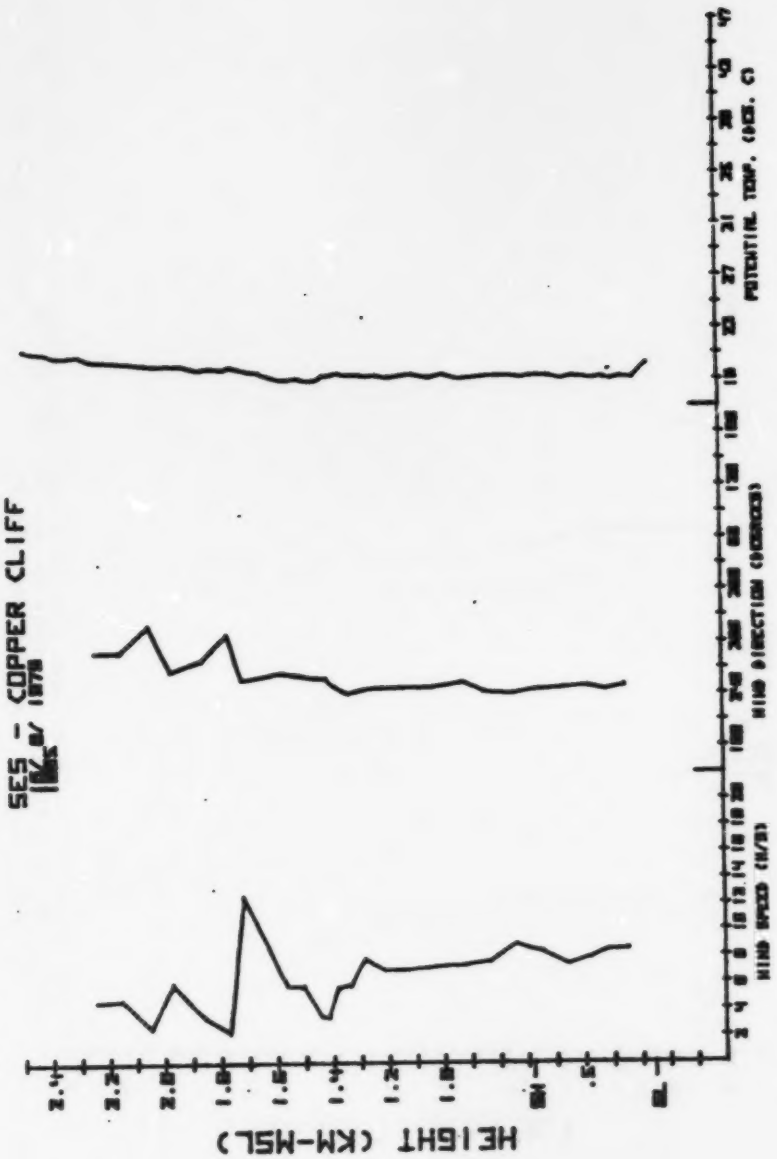

SES - COPPER CLIFF
15/8/ 1979
HEIGHT (KM-MSL)
POTENTIAL TEMP. (DEG. C)
WIND DIRECTION (DEGREES)
WIND SPEED (M/S)

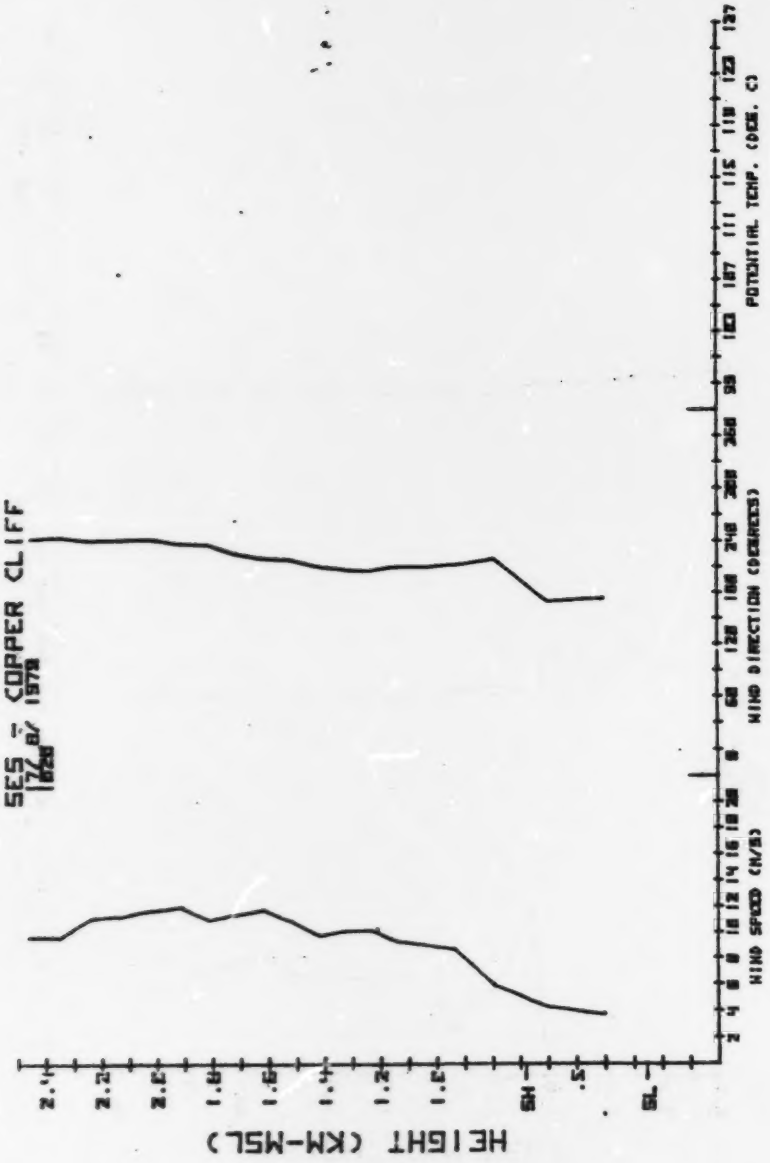

SES - COPPER CLIFF
HEIGHT (KM-MSL)
POTENTIAL TEMP. (DEG. C)

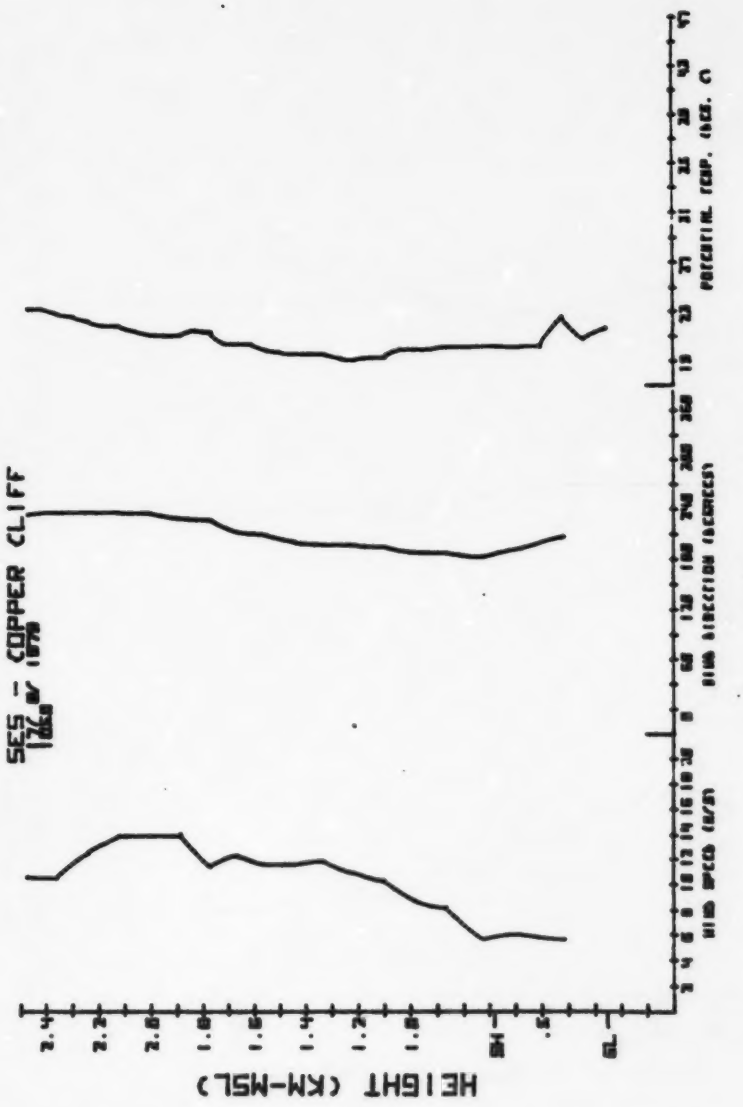

SES - COPPER CLIFF
HEIGHT (KM-MSL)

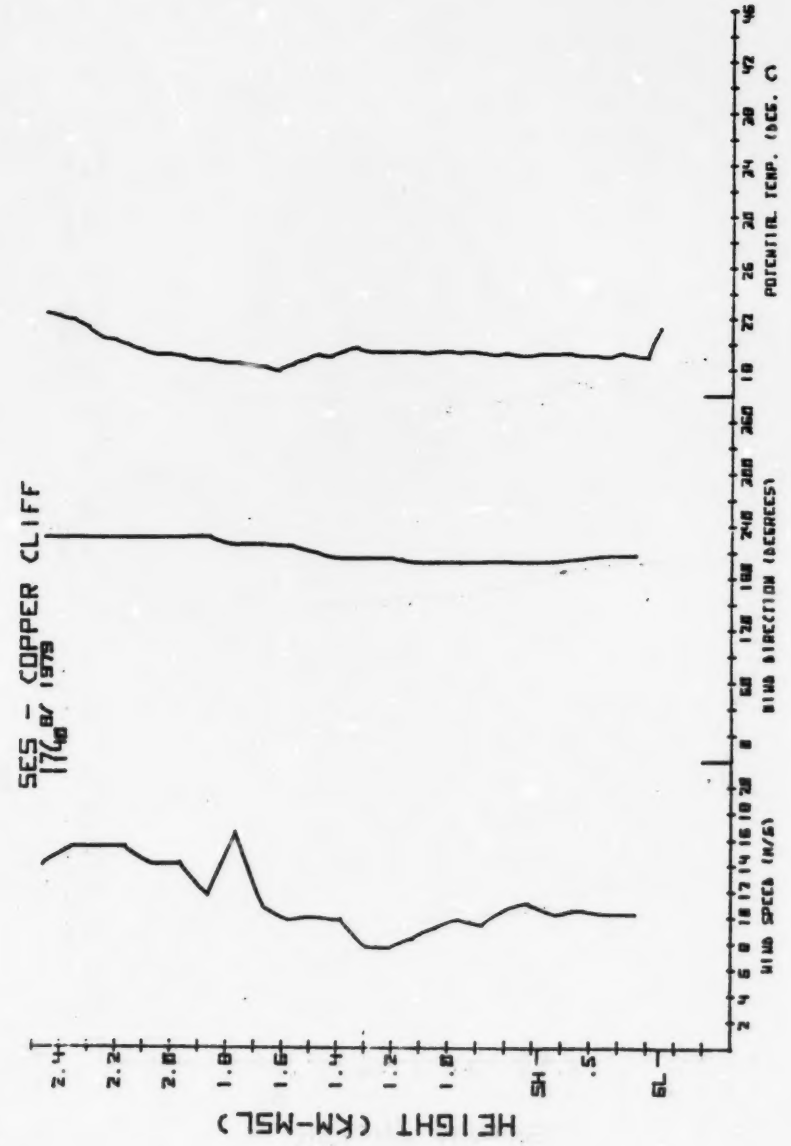

SES - COPPER CLIFF
HEIGHT (KM-MSL)

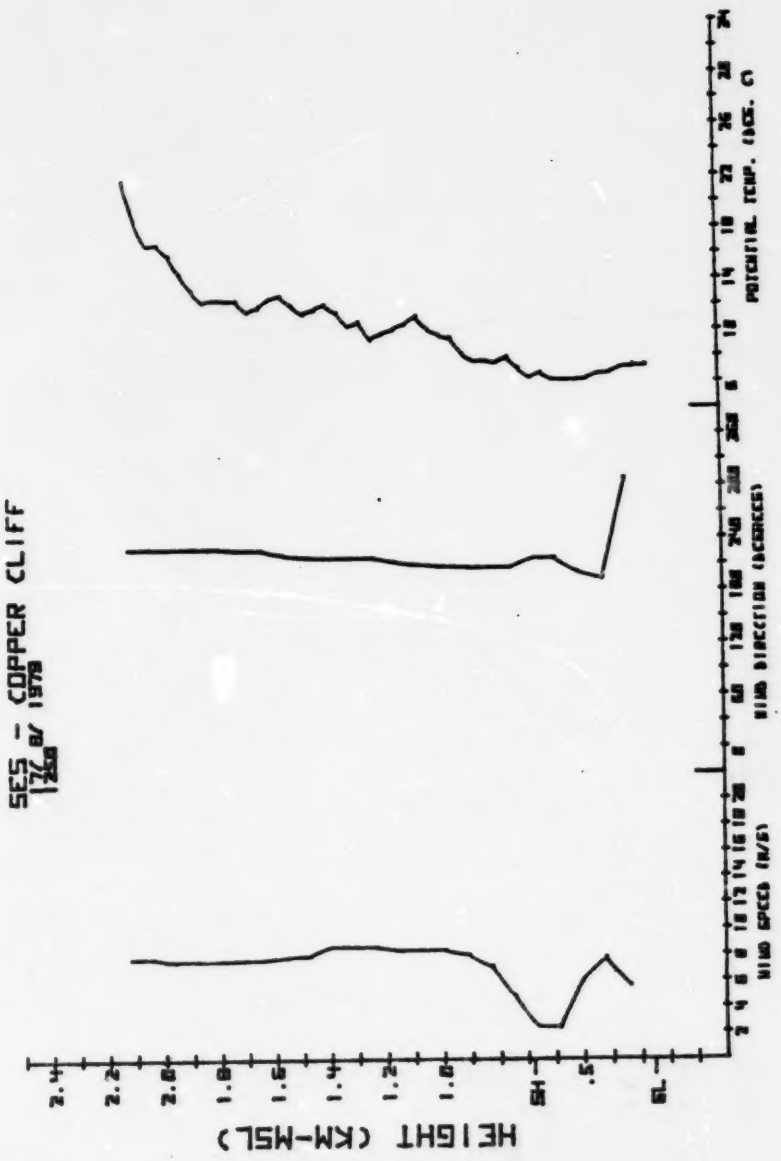

SES - COPPER CLIFF
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.5
SH
GL

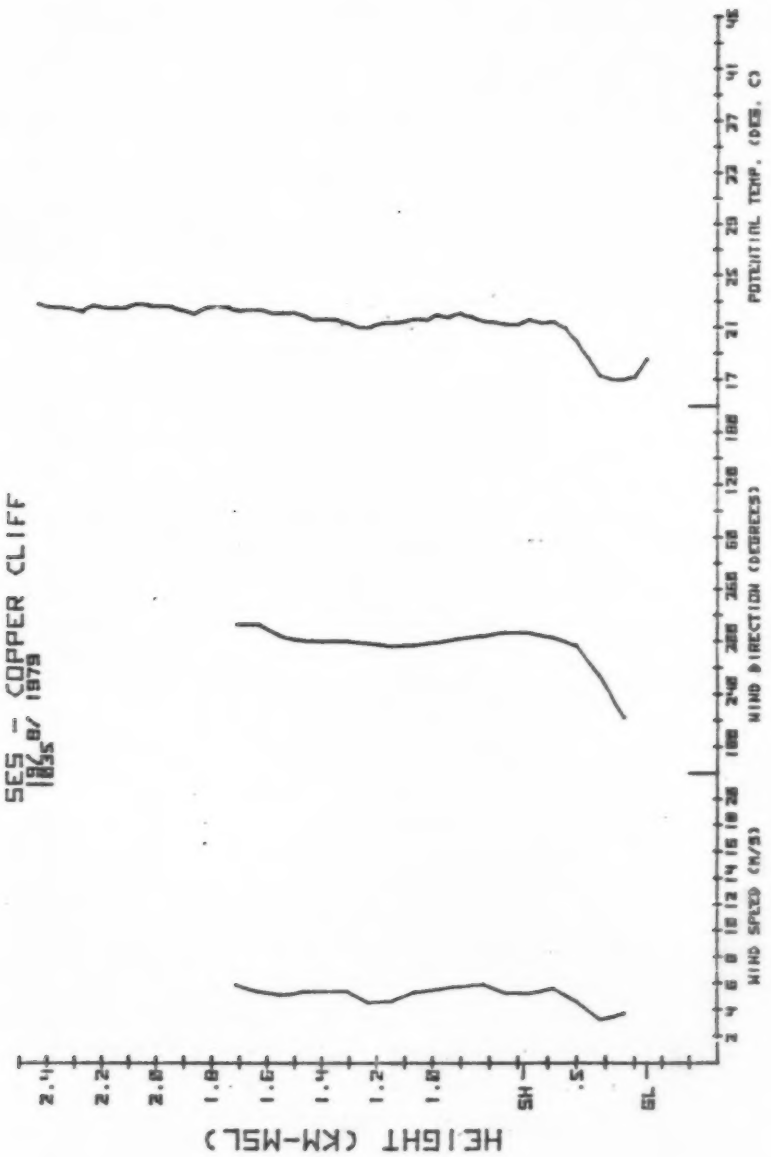

SES - COPPER CLIFF
HEIGHT (KM-MSL)
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG. C)

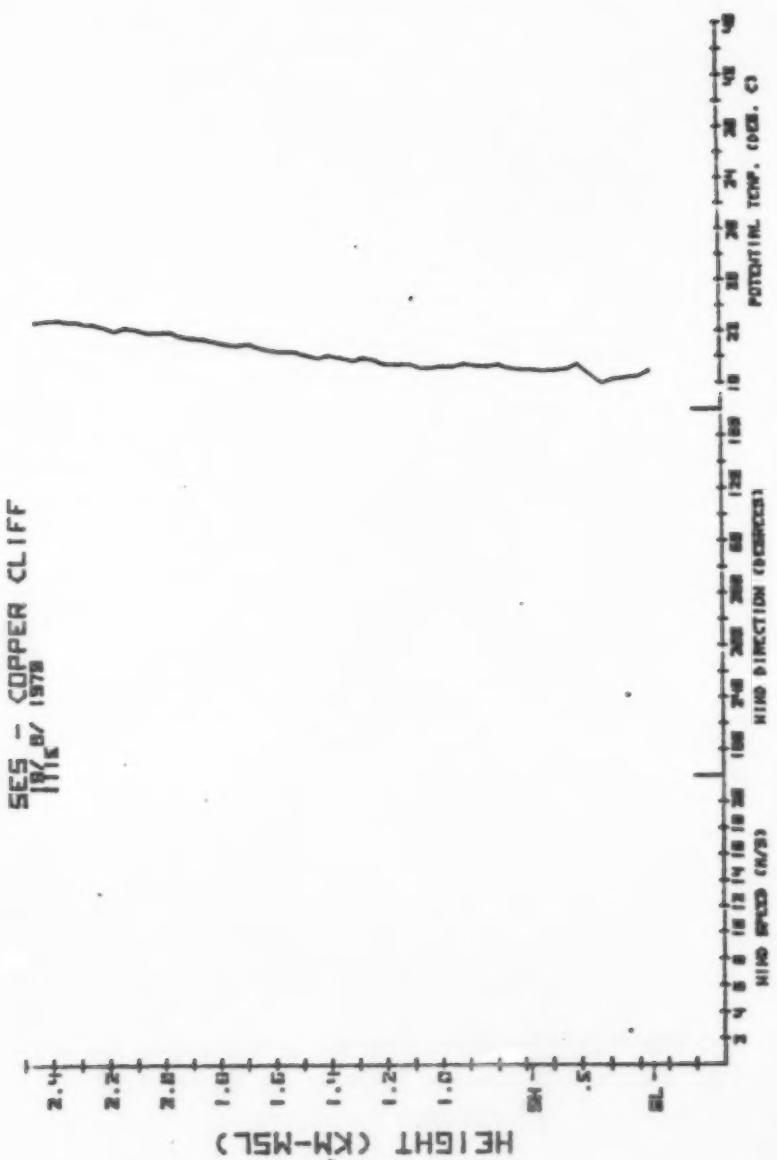

SES - COPPER CLIFF
1978
HEIGHT (KM-MSL)
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG. C)

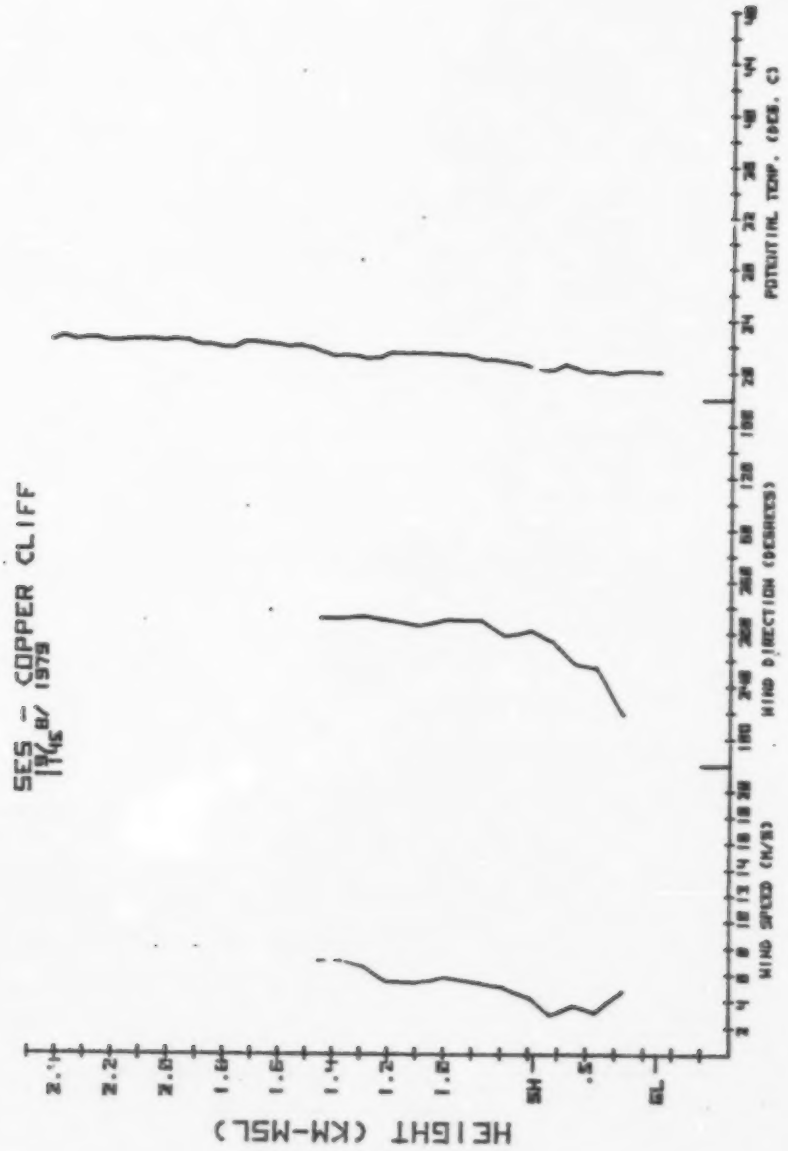

SES - COPPER CLIFF
HEIGHT (KM-MSL)

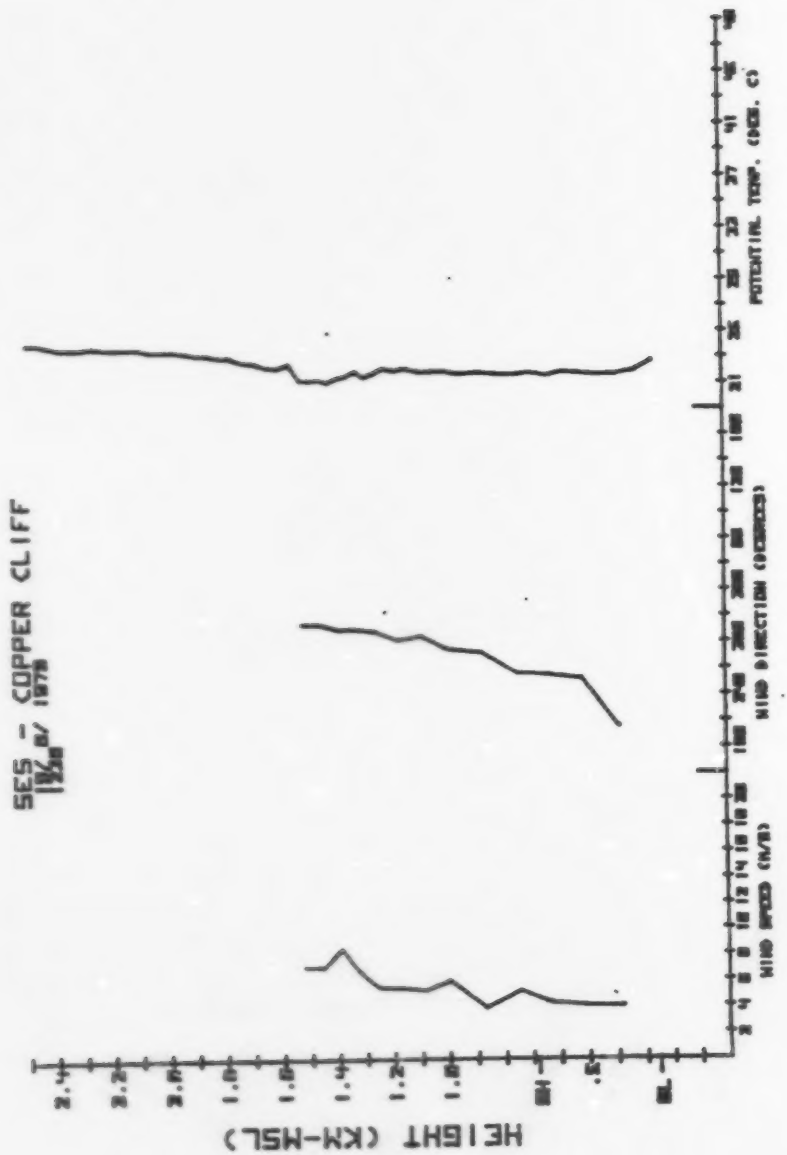

SES - COPPER CLIFF
174 GB/ 1979
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.5
HS
GL
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG. C)

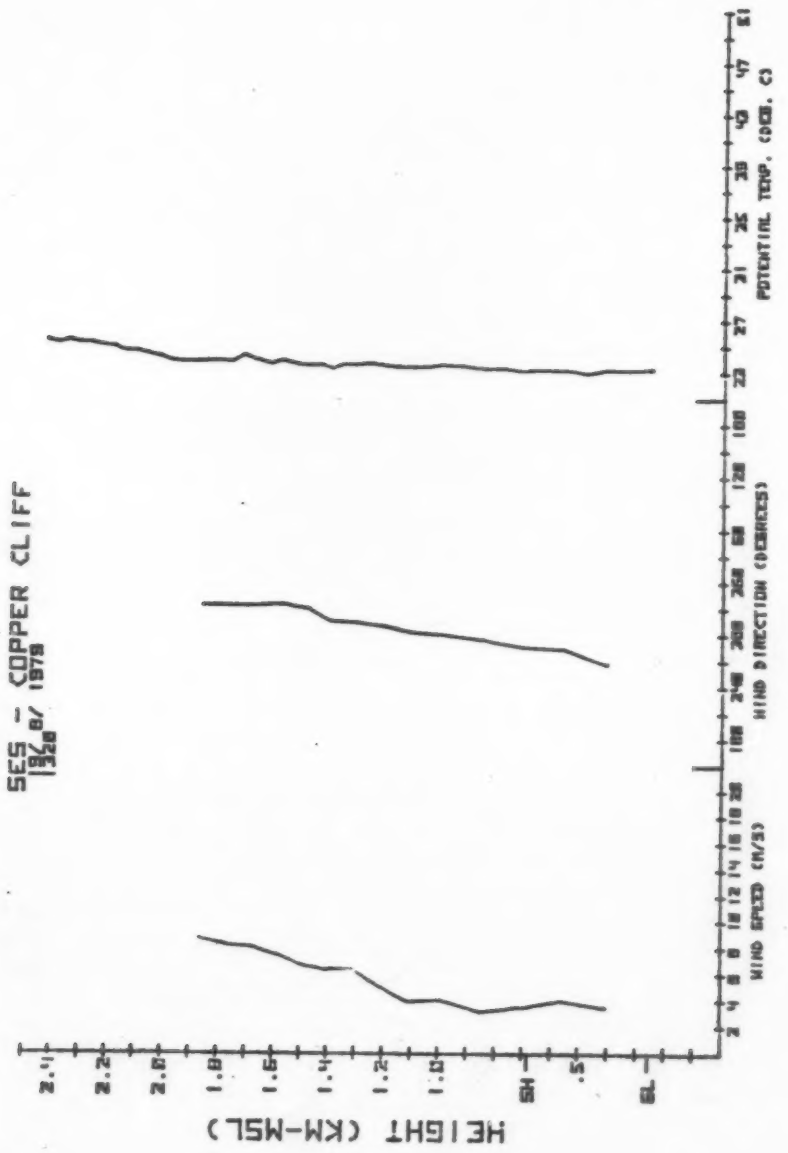

SES - COPPER CLIFF
HEIGHT (KM-MSL)
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG. C)

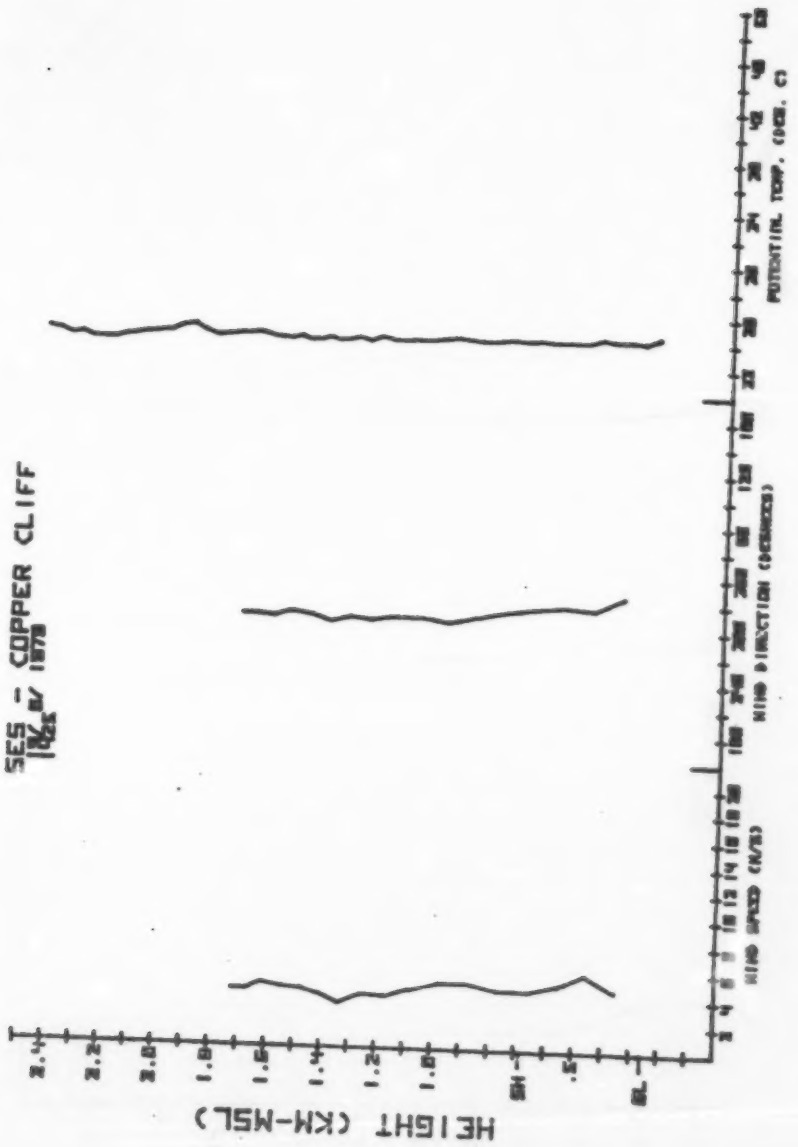

SES - COPPER CLIFF
1978
HEIGHT (KM-MSL)
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG. C)

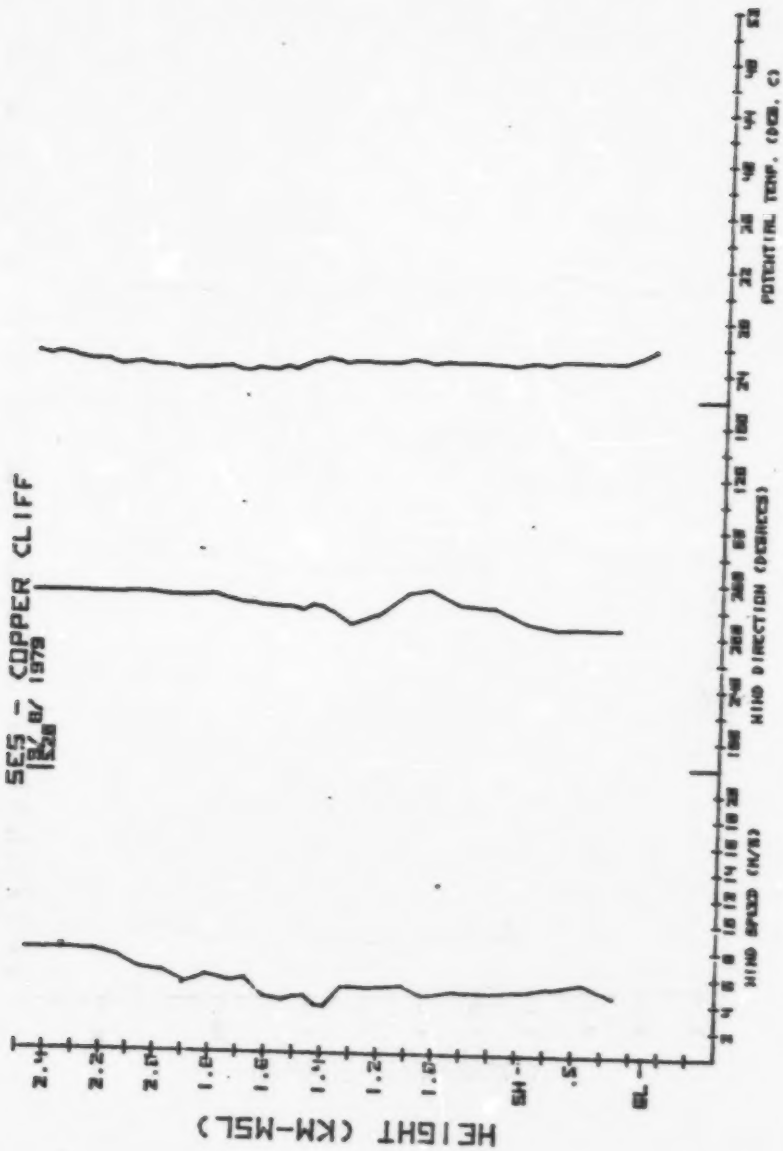

SES - COPPER CLIFF
18/8/ 1978
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
MSL
WIND SPEED (KNTS)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG. C)

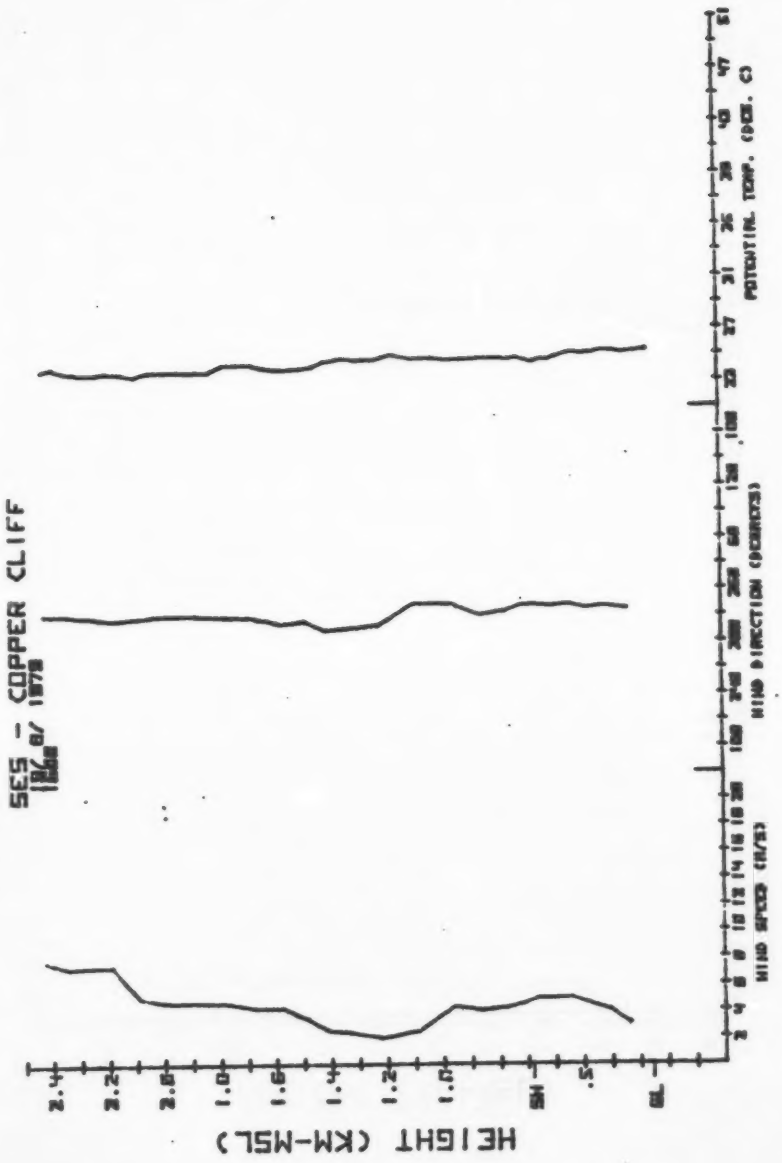

SES - COPPER CLIFF
1979
HEIGHT (KM-MSL)
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG. C)

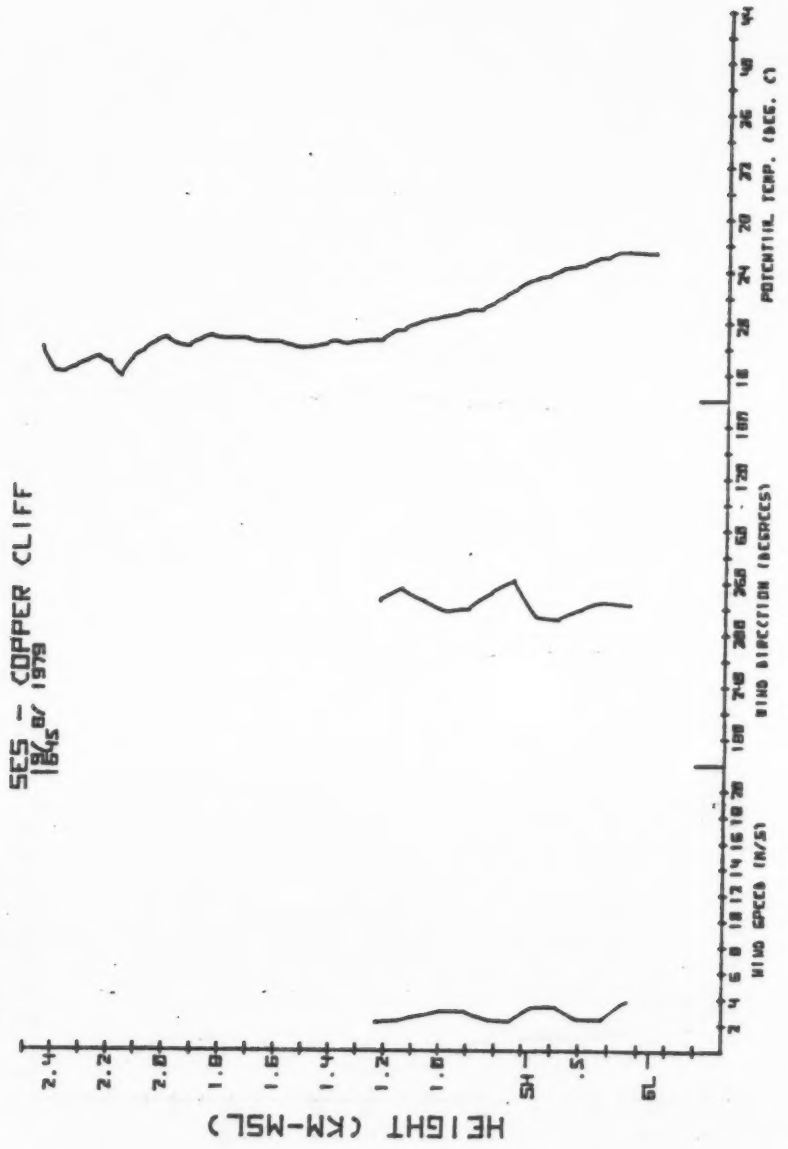

SES - COPPER CLIFF
HEIGHT (KM-MSL)
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG. C)

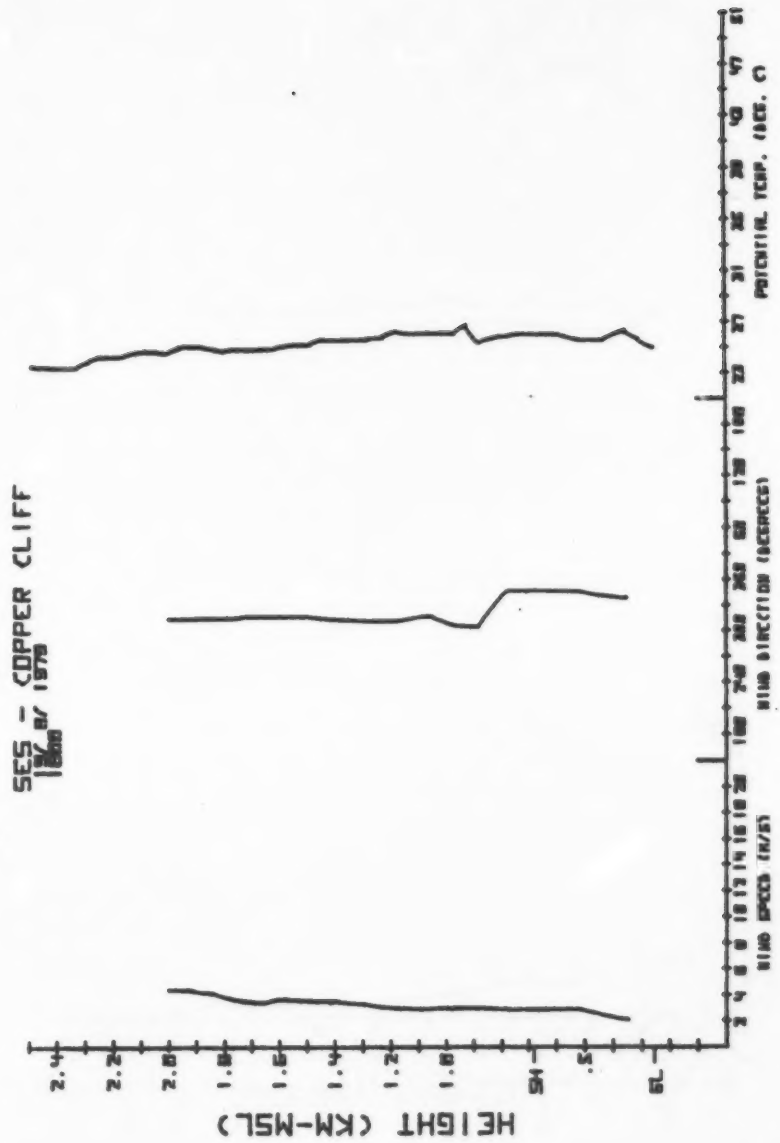

SES - COPPER CLIFF
1978
HEIGHT (KM-MSL)
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG. C)

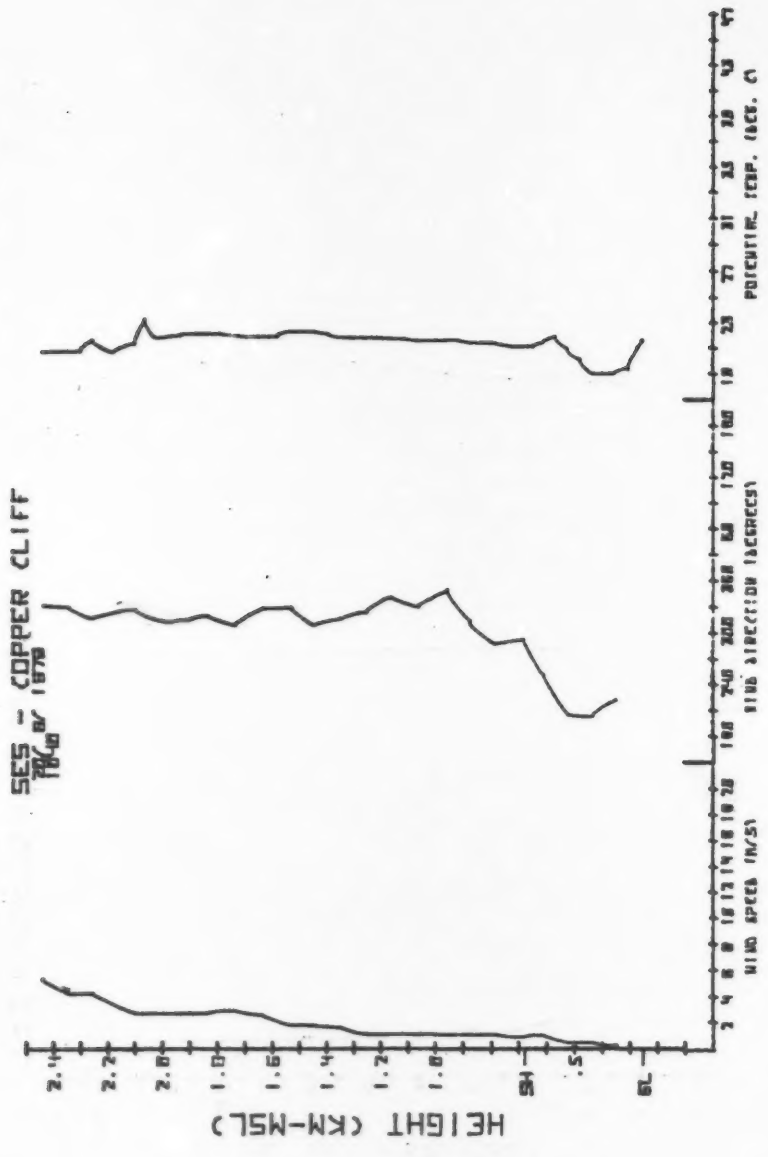

SES - COPPER CLIFF
HEIGHT (KM-MSL)
POTENTIAL TEMP. (DEG. C)


SES - COPPER CLIFF
HEIGHT (KM-MSL)
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG. C)


SES - COPPER CLIFF
HEIGHT (KM-MSL)
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG. C)


SES - COPPER CLIFF
18/8/ 1979
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.5
HS
TS
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG. C)


SES - COPPER CLIFF
HEIGHT (KM-MSL)


SES - COPPER CLIFF
HEIGHT (KM-MSL)
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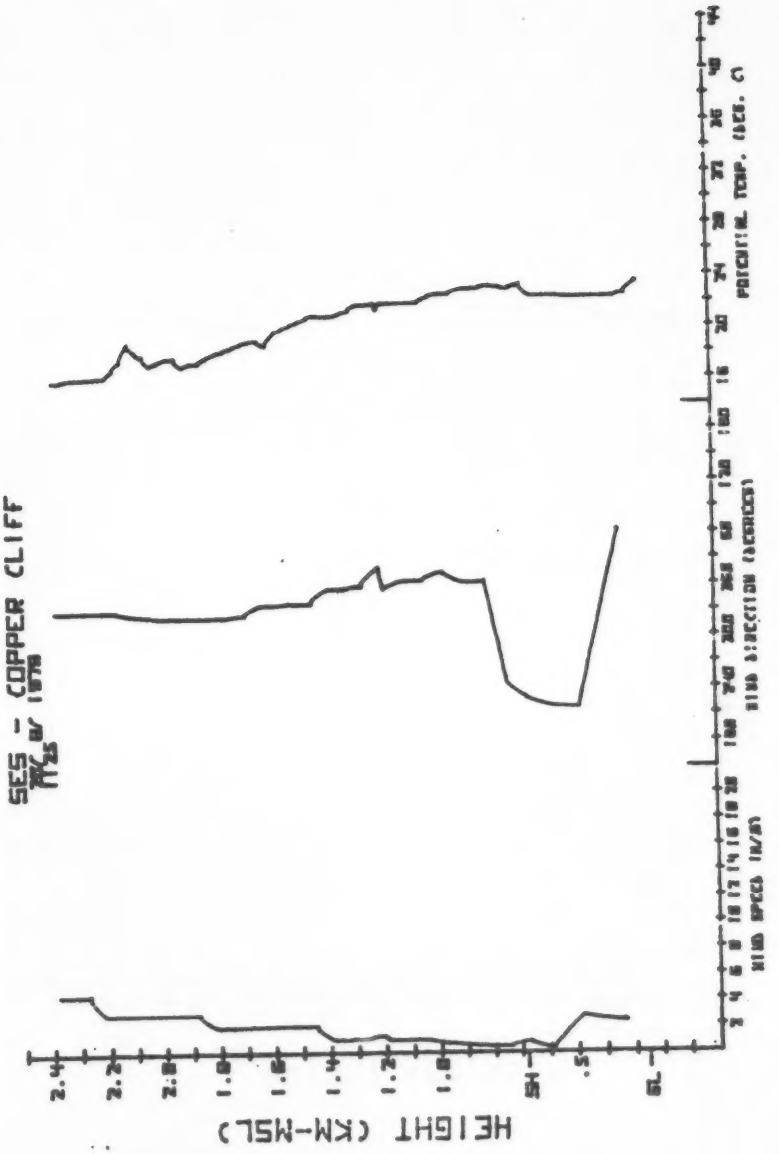
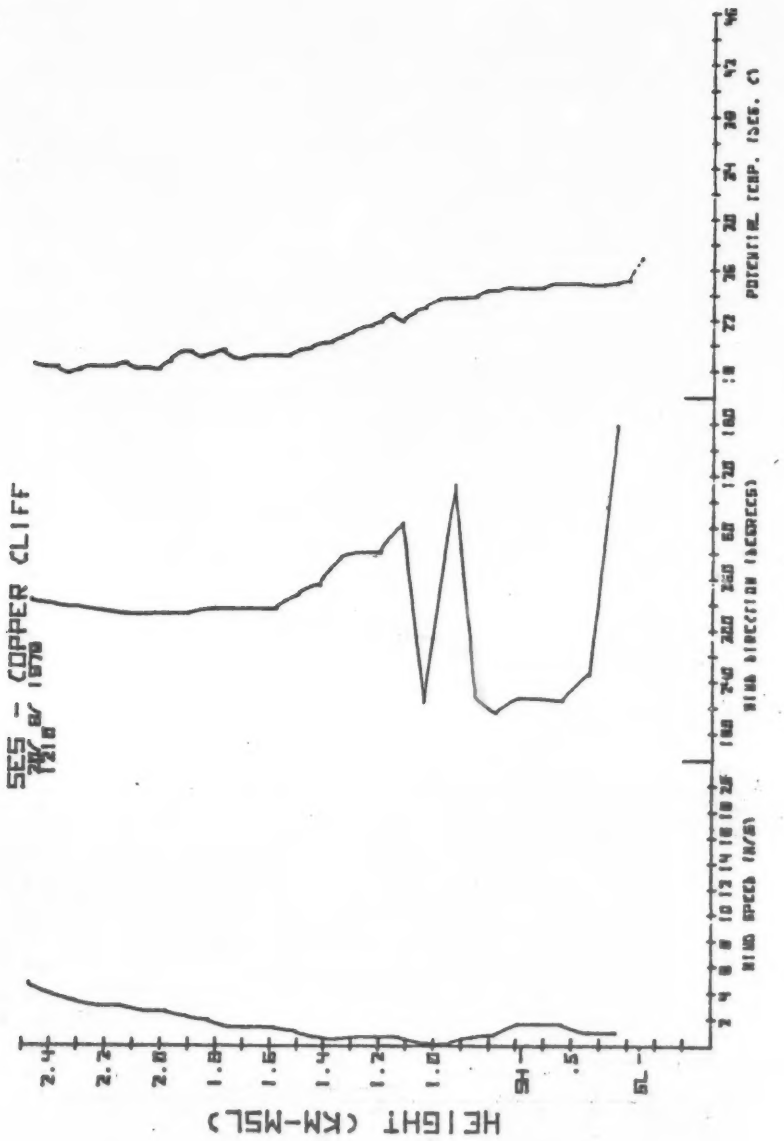
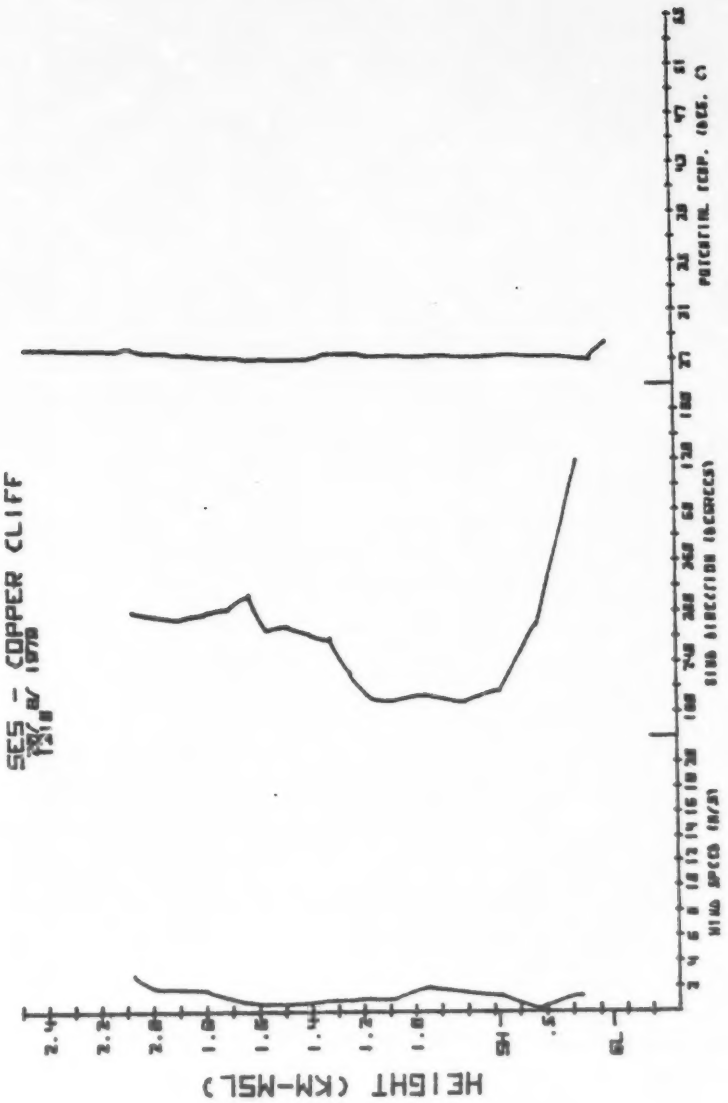
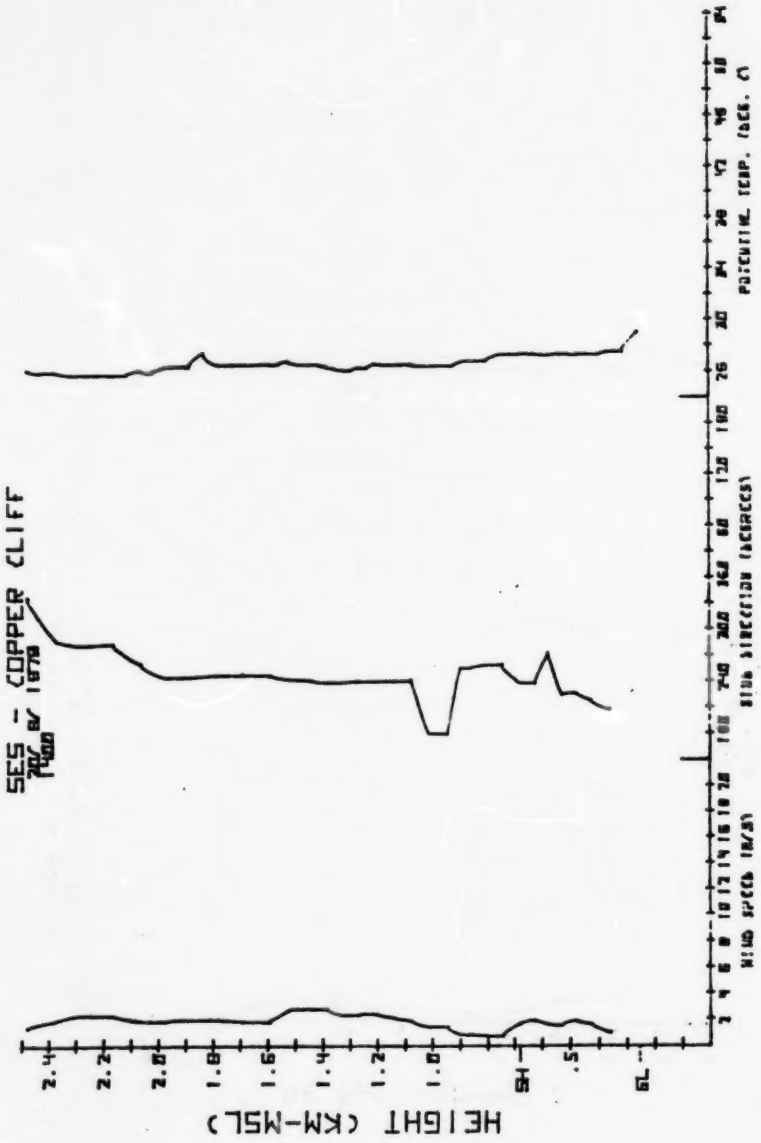
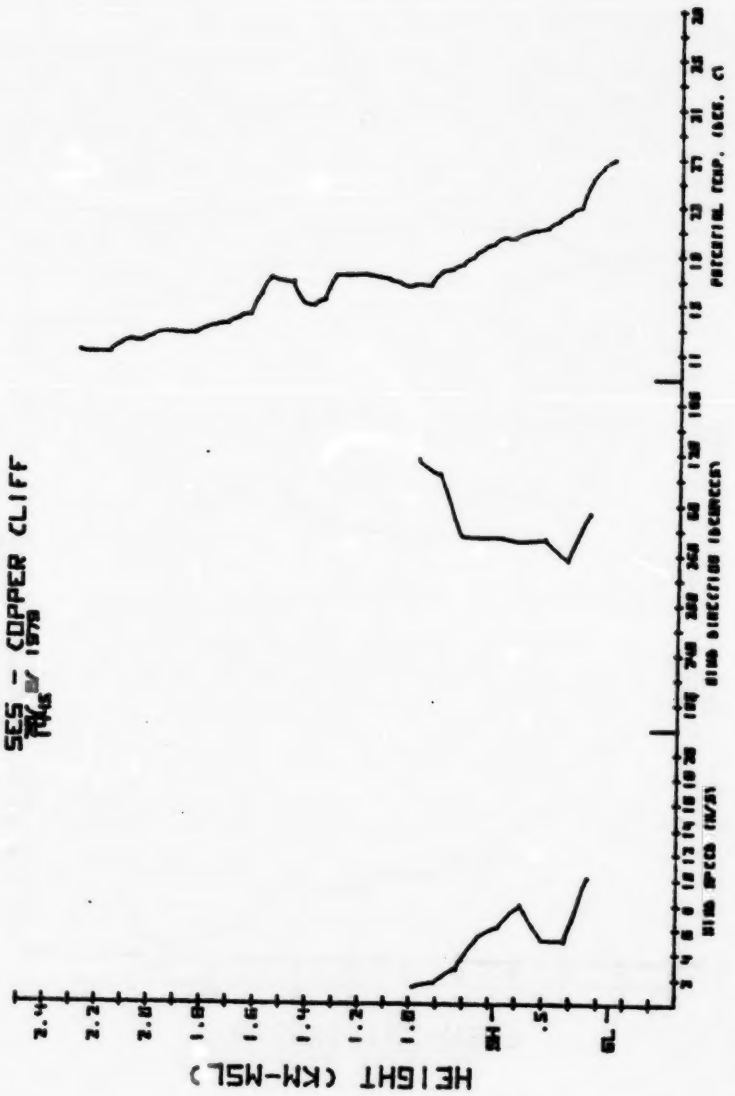
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
SH
SL

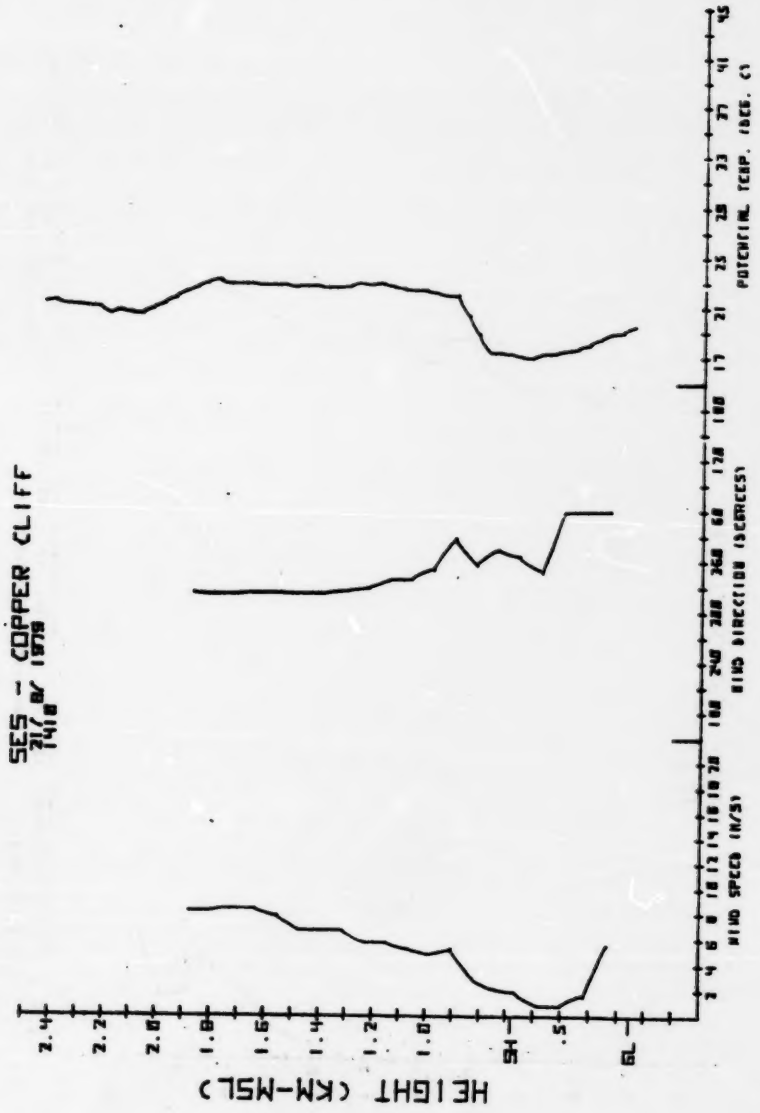

SES - COPPER CLIFF
HEIGHT (KM-MSL)

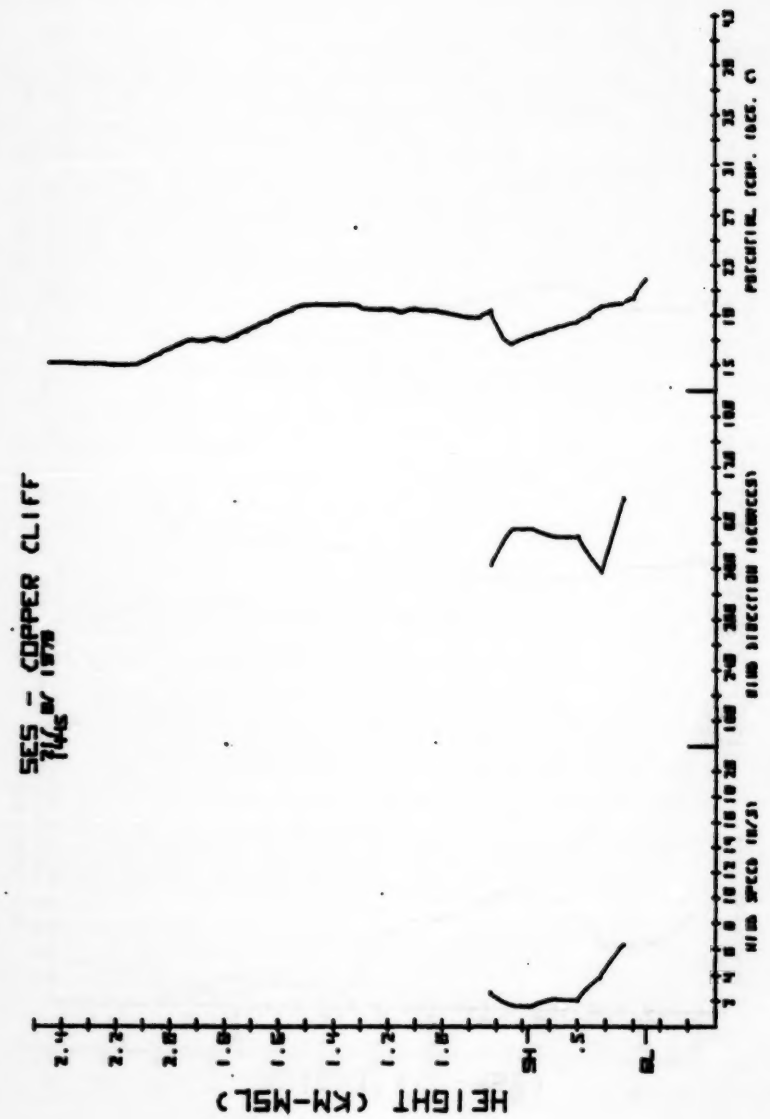

SES - COPPER CLIFF
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.5
SH
SL

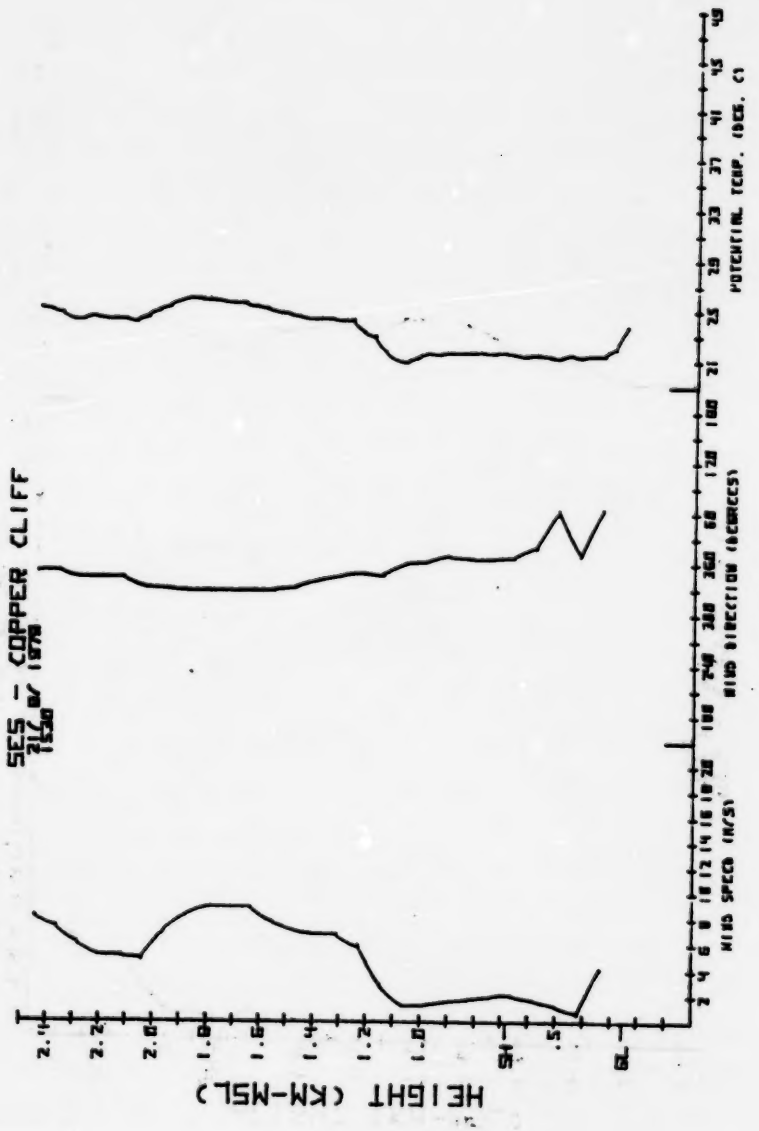

SES - COPPER CLIFF
HEIGHT (KM-MSL)

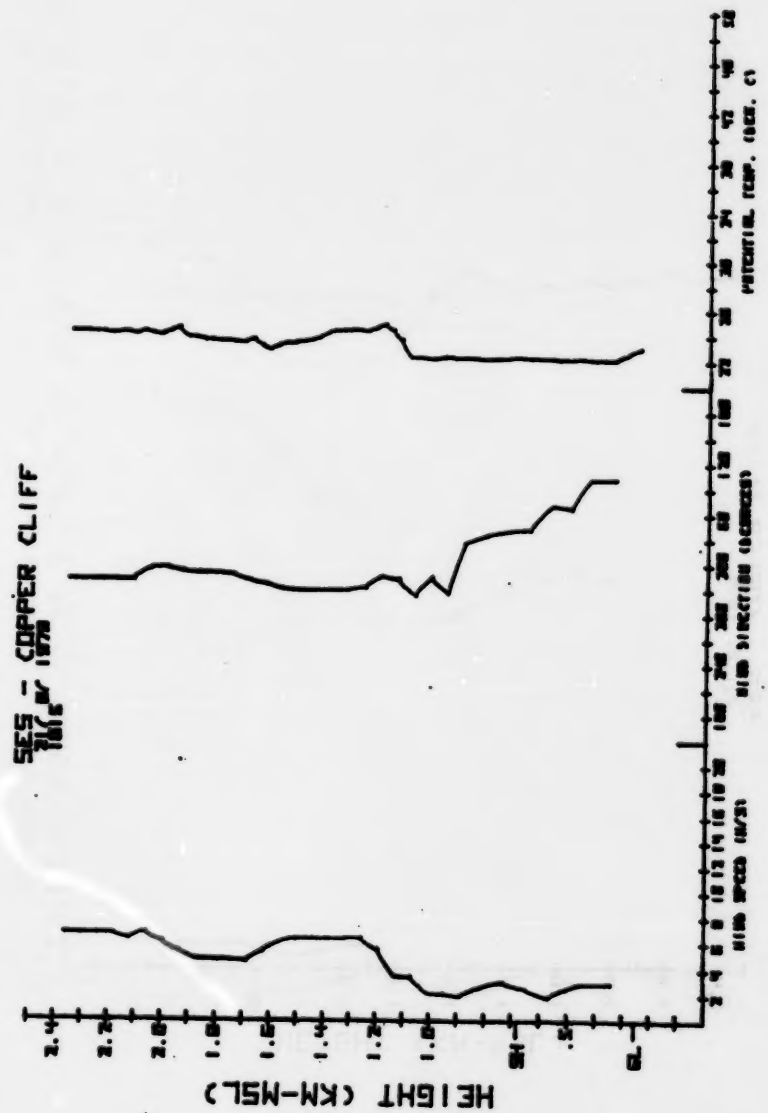

SES - COPPER CLIFF
HEIGHT (KM-MSL)

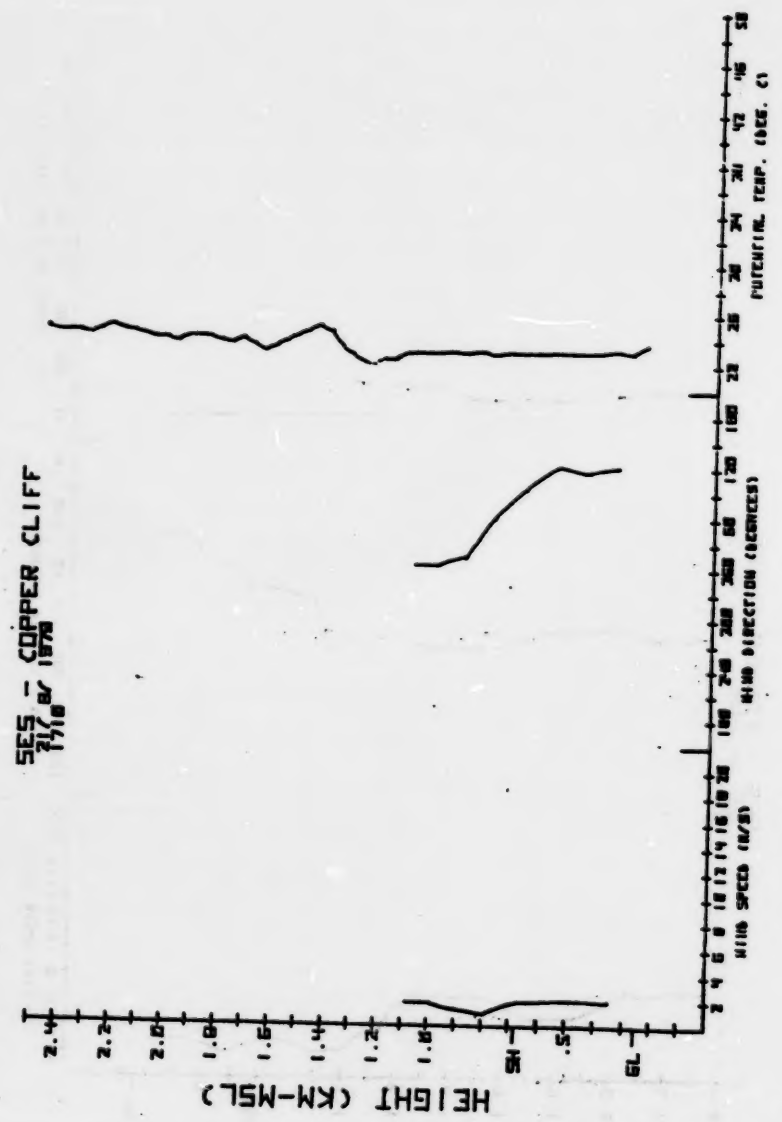

SES - COPPER CLIFF
HEIGHT (KM-MSL)

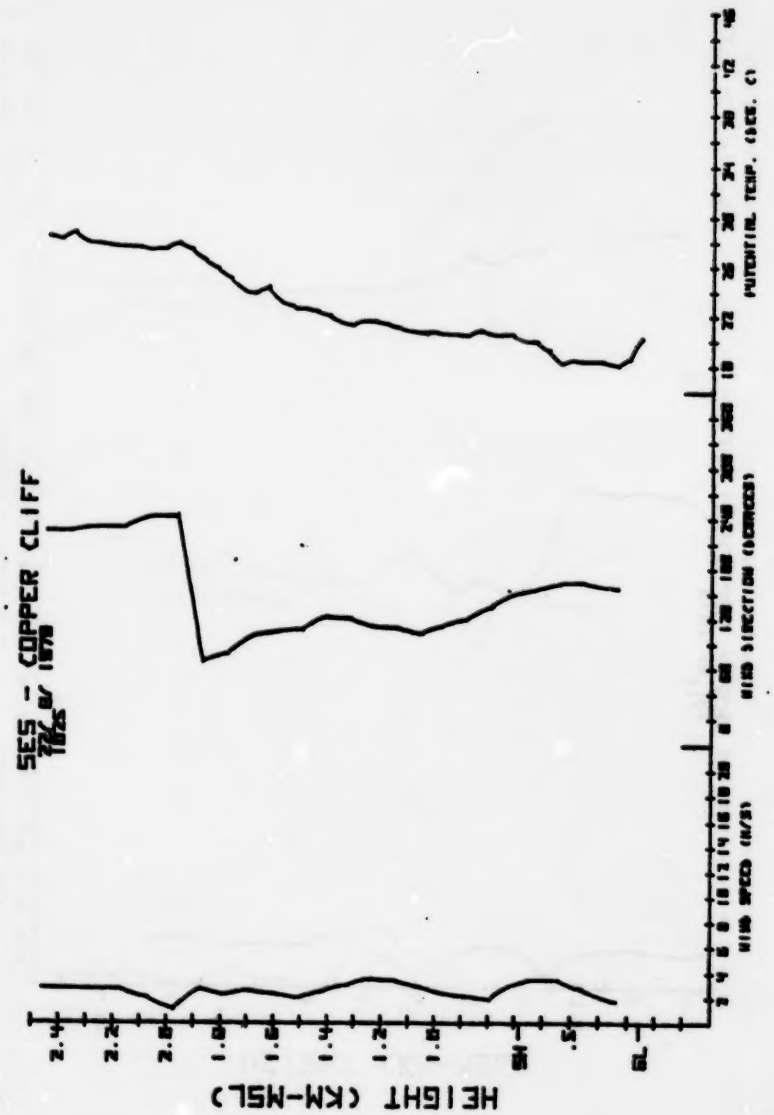

SES - COPPER CLIFF
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.5
HS
GL
WIND SPEED (M/S)
WIND DIRECCION (DEGREES)
POTENTIAL TEMP. (DEG. C)

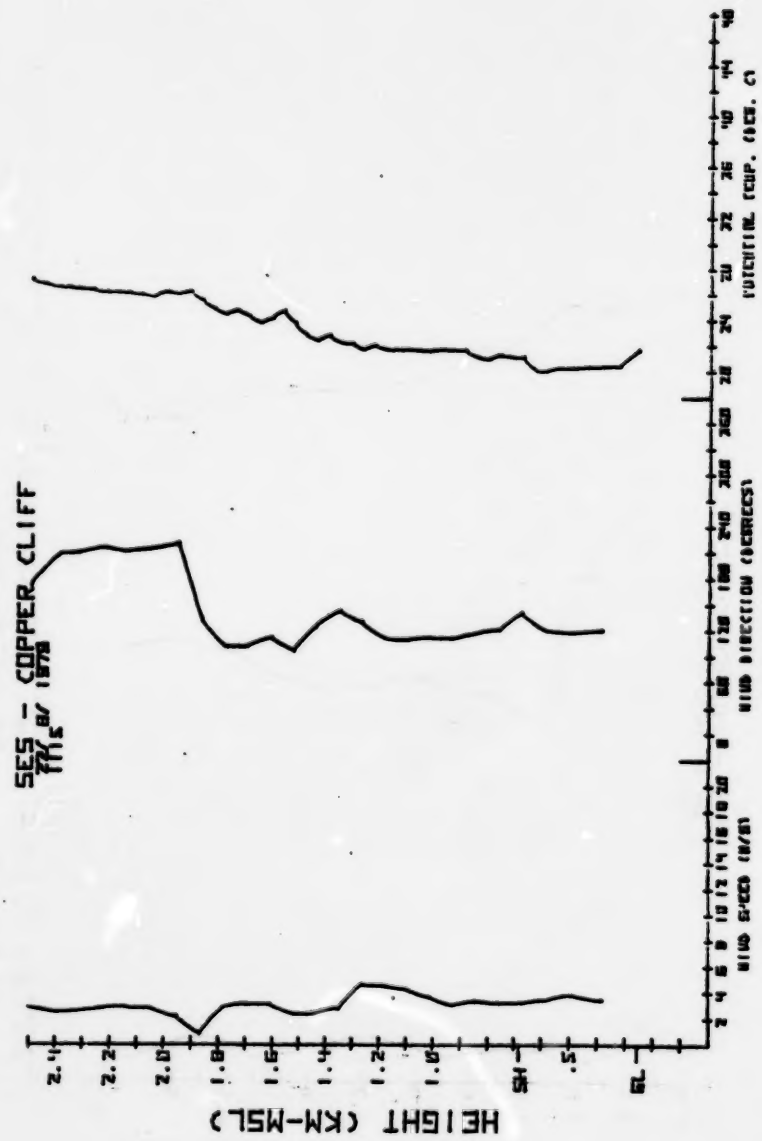

SES - COPPER CLIFF
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
HS
SL

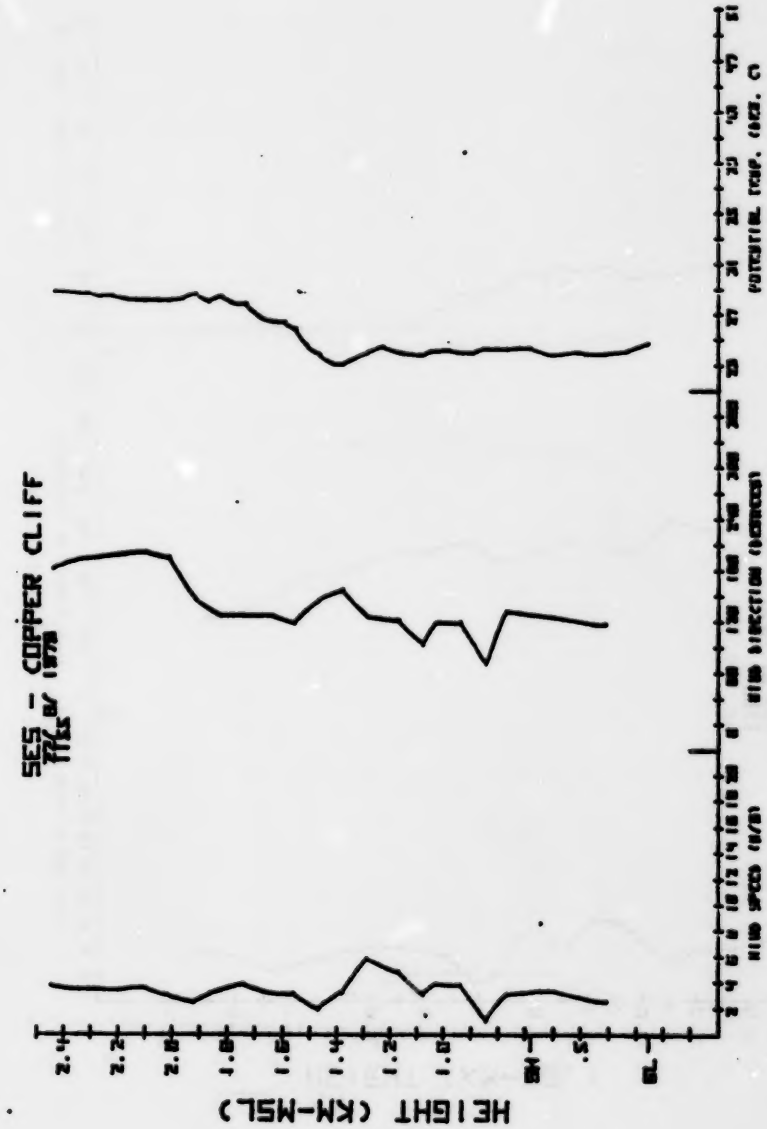

SES - COPPER CLIFF
HEIGHT (KM-MSL)
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG. C)

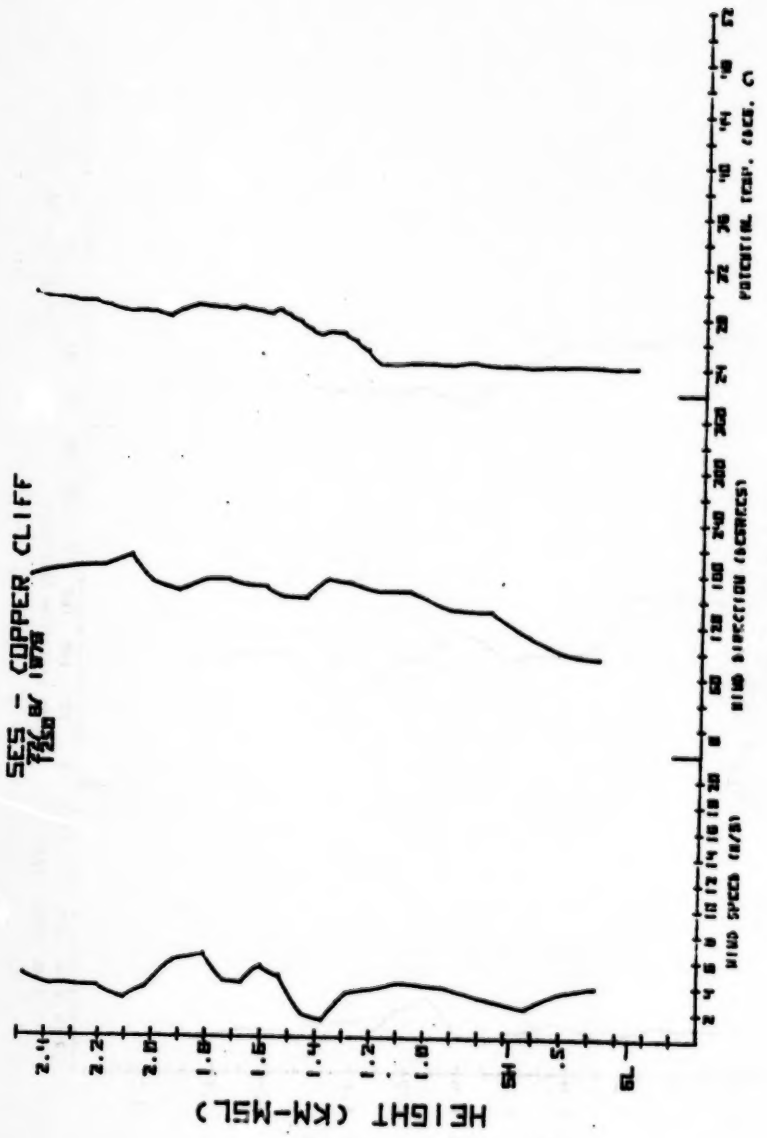

SES - COPPER CLIFF
HEIGHT (KM-MSL)

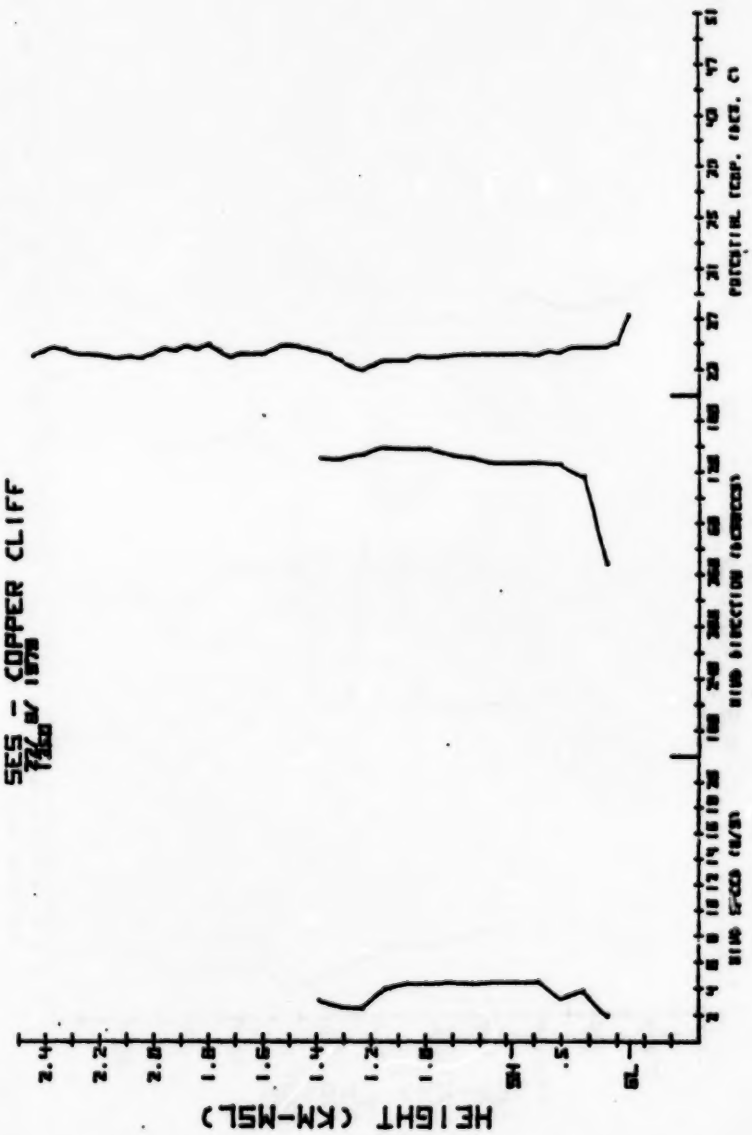

SES - COPPER CLIFF
HEIGHT (KM-MSL)
POTENTIAL TEMP. (DEG. C)
WIND DIRECTION (DEGREES)
WIND SPEED (M/S)

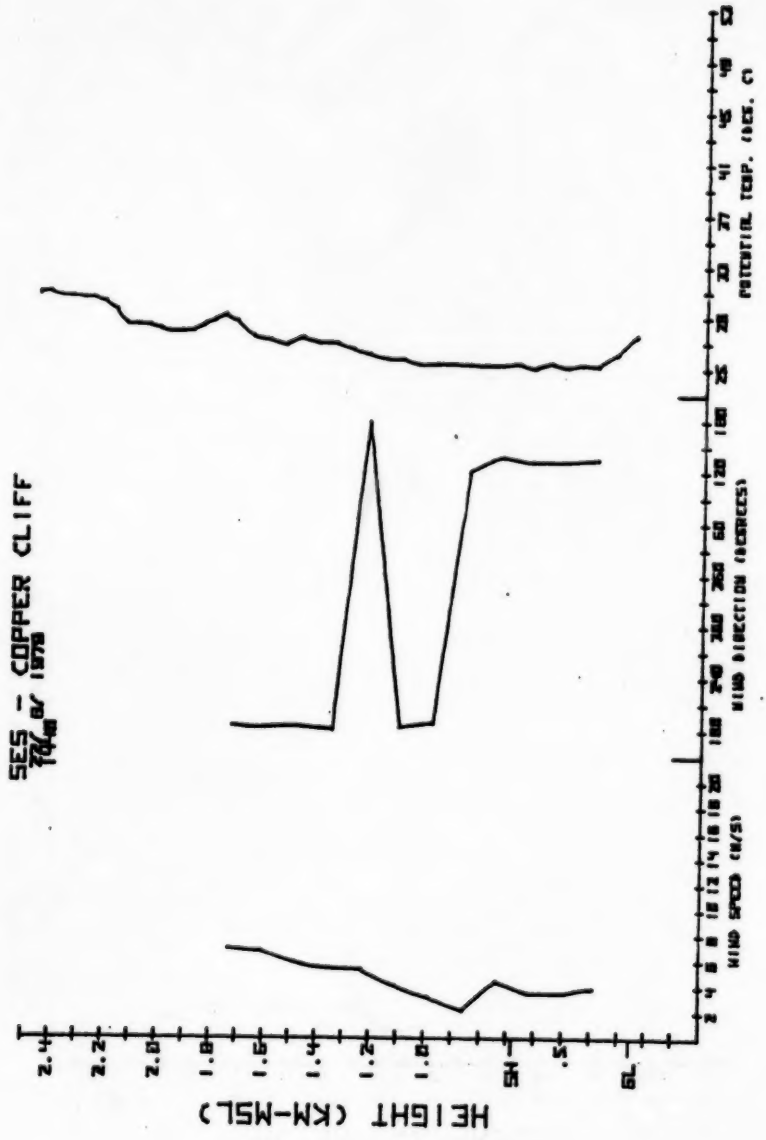

SES - COPPER CLIFF
HEIGHT (KM-MSL)

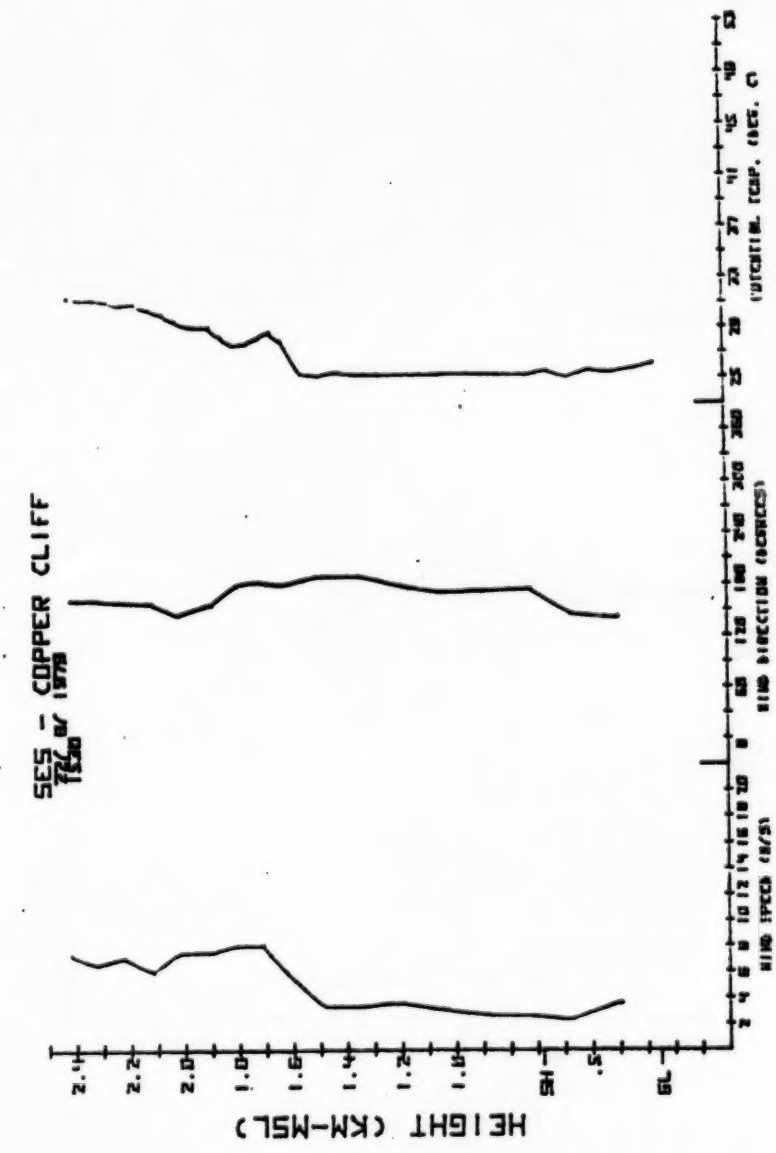

SES - COPPER CLIFF
HEIGHT (KM-MSL)


SES - COPPER CLIFF
HEIGHT (KM-MSL)


SES - COPPER CLIFF
HEIGHT (KM-MSL)
TB
HS
TL
WIND SPEED (KNOTS)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG. C)


SES - COPPER CLIFF
HEIGHT (KM-MSL)


SES - COPPER CLIFF
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
POTENTIAL TEMP. (DEG. C)
WIND DIRECTION (DEGREES)
WIND SPEED (M/S)


SES - COPPER CLIFF
HEIGHT (KM-MSL)
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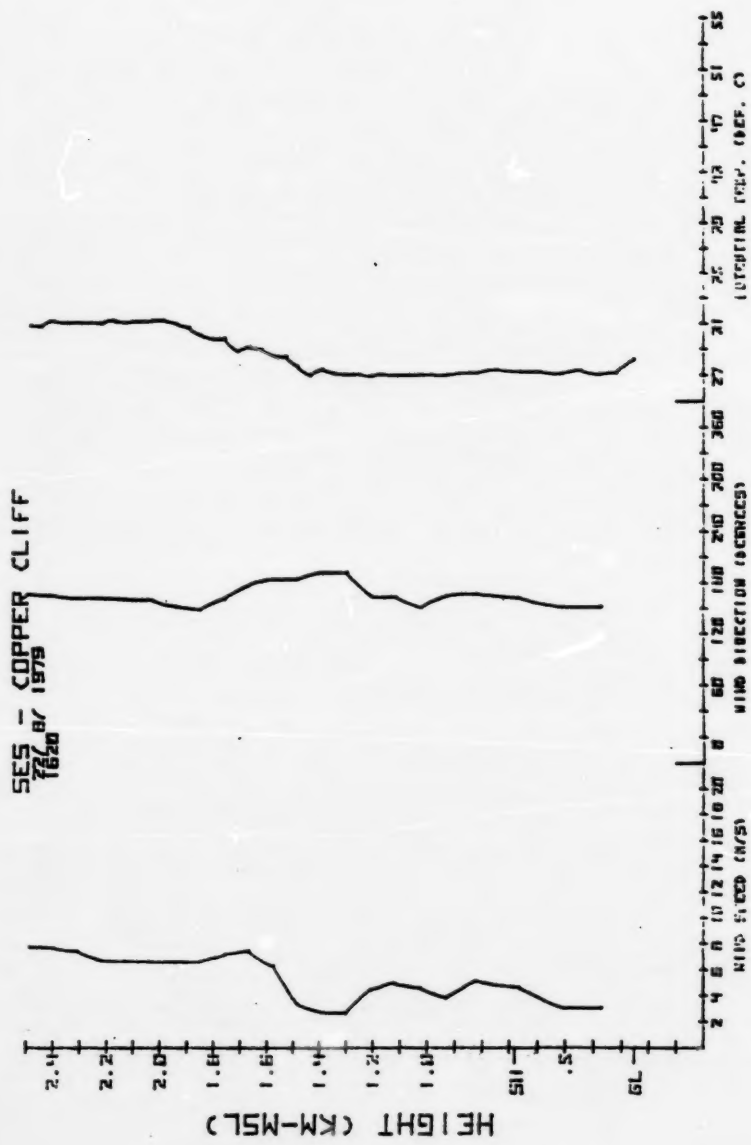
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
HS
SL


SES - COPPER CLIFF
72Z 8/ 1979
1620
HEIGHT (KM-MSL)
2.4
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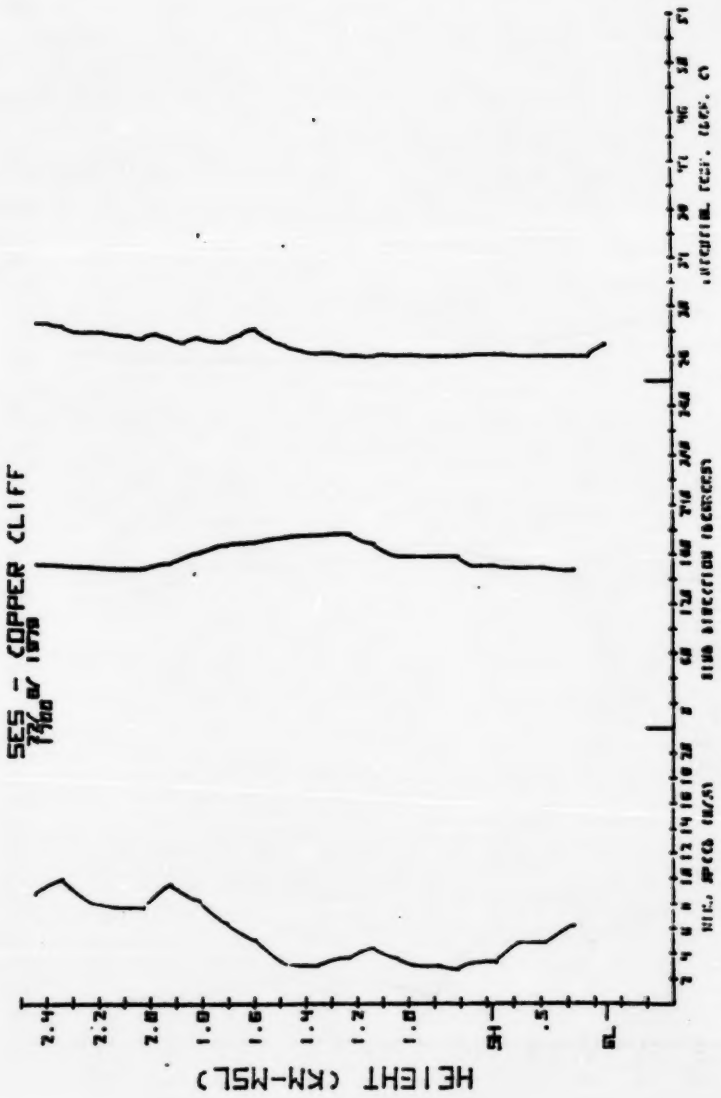
1.8
1.6
1.4
1.2
1.0
.5
GL


SES - COPPER CLIFF
HEIGHT (KM-MSL)
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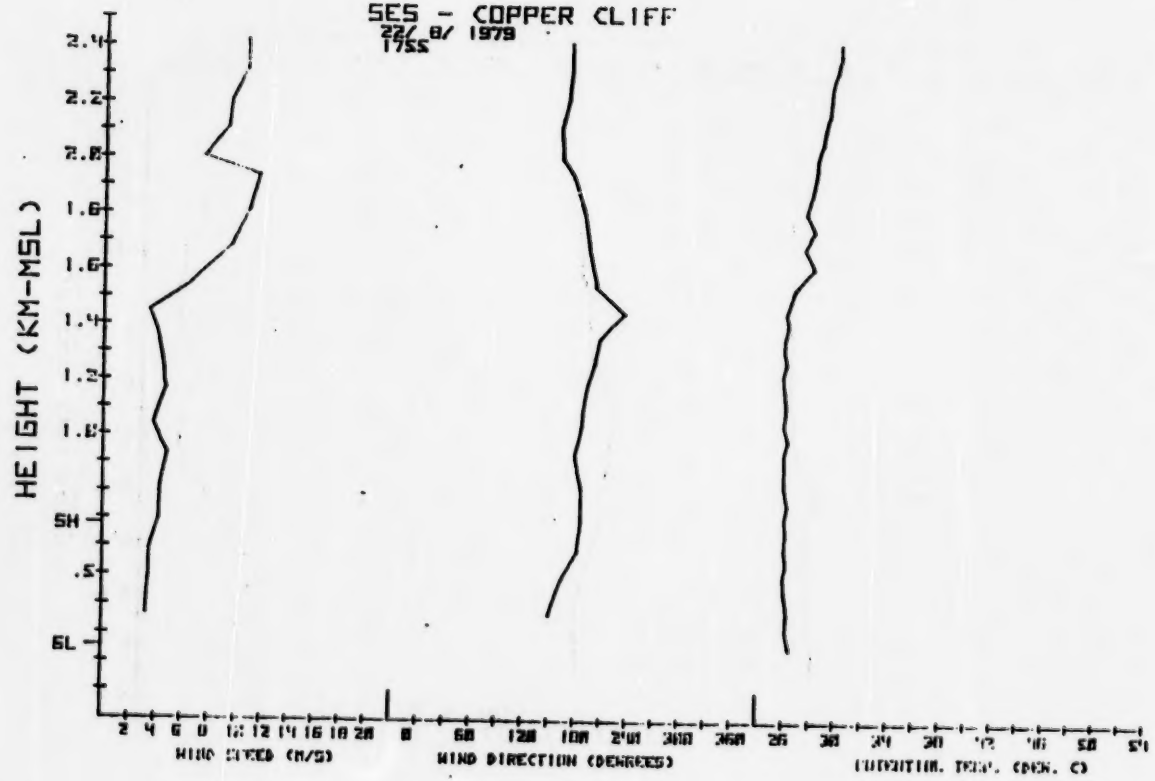
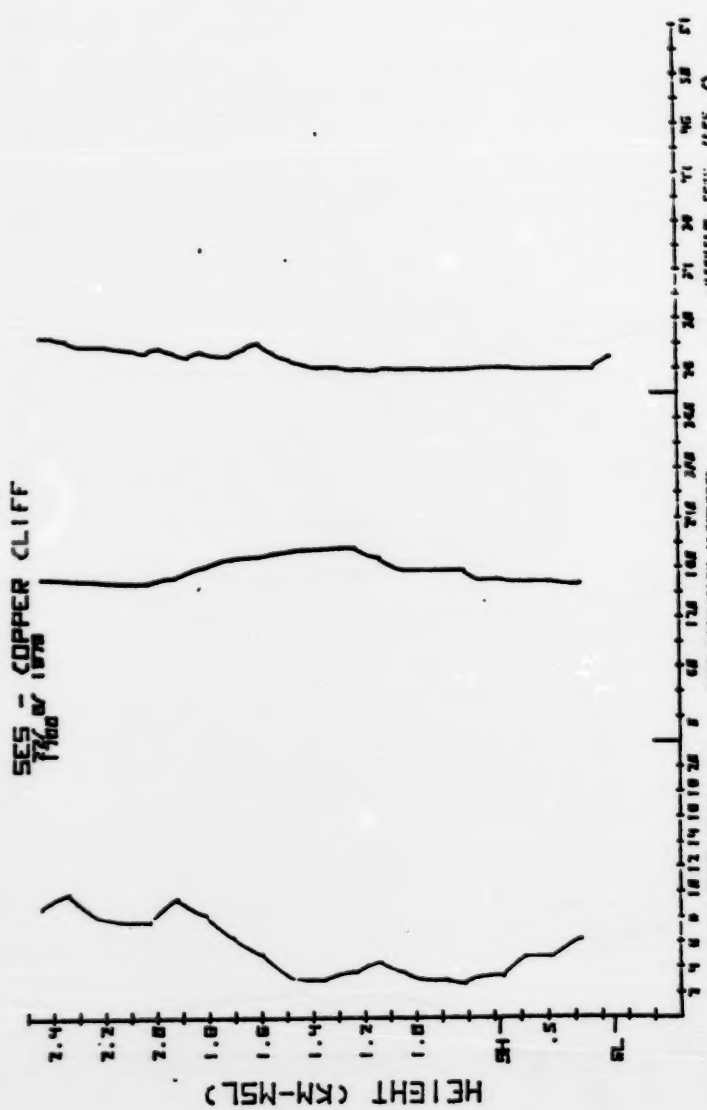
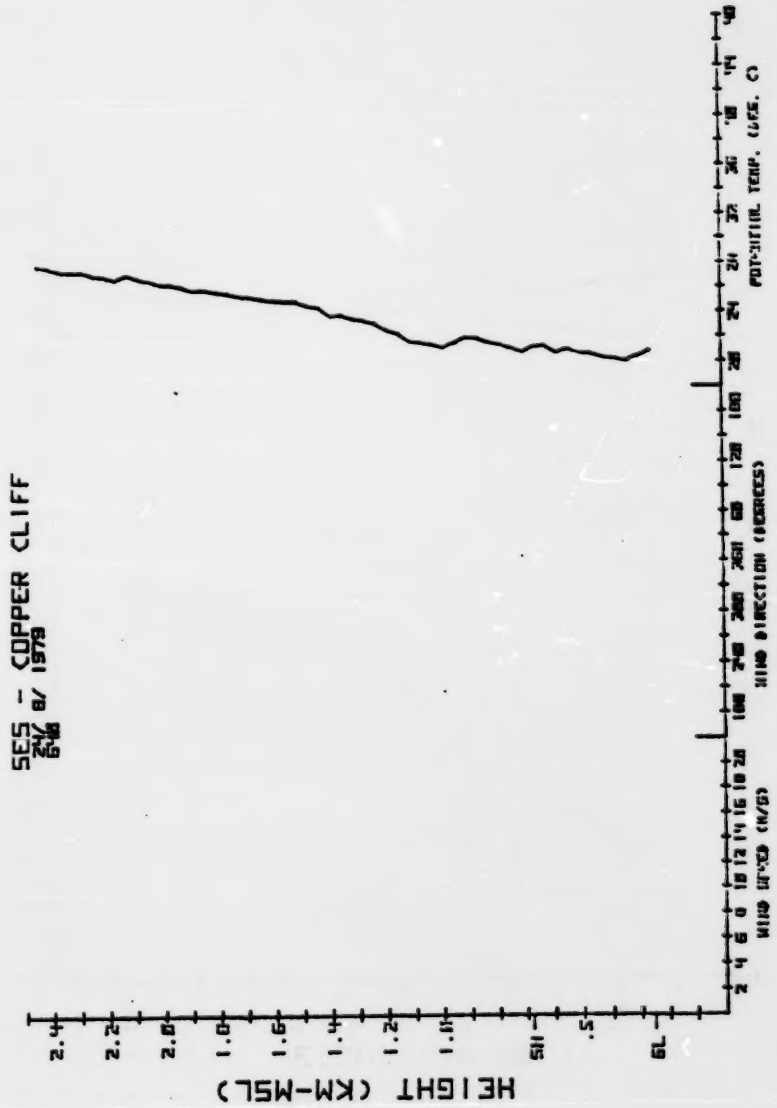
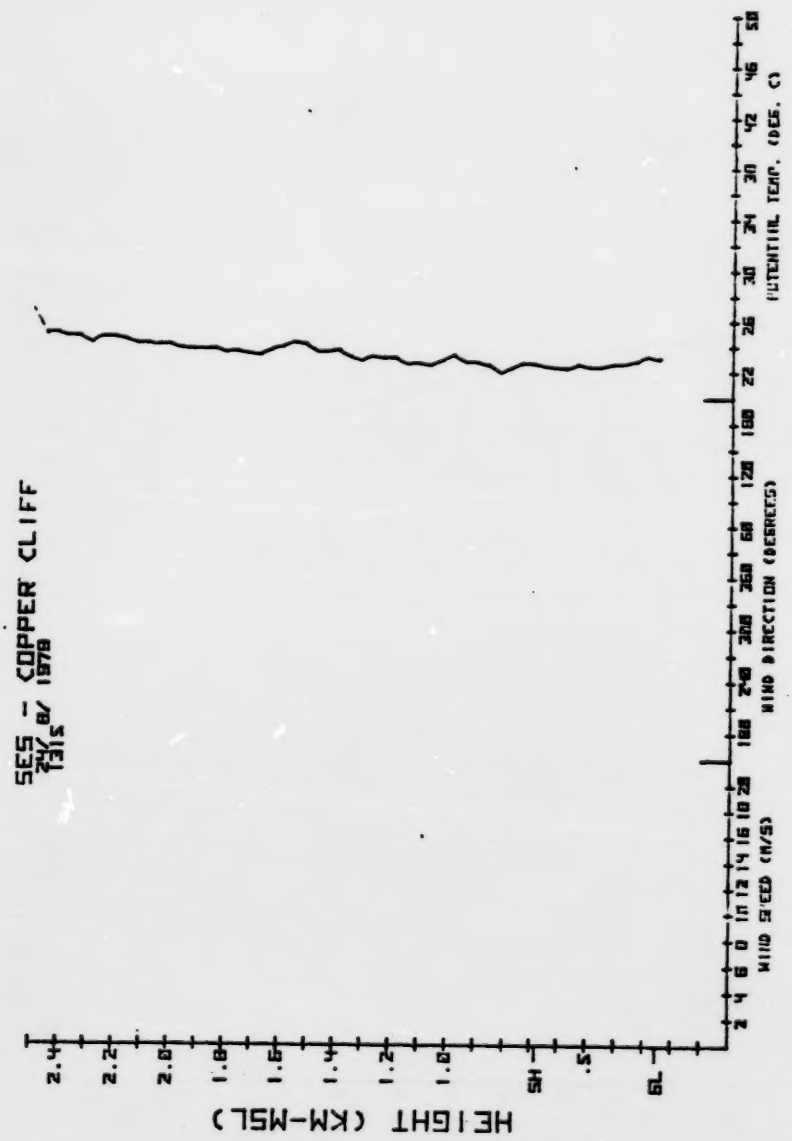
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
SH
.5
SL


SES - COPPER CLIFF
22/ 8/ 1979
1755
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
SH
.5
GL
2 4 6 8 12 14 16 18 20
WIND SPEED (M/S)
0 60 120 180 240 300 360
WIND DIRECTION (DEGREES)
26 30 34 38 42 46 50 54
TEMPERATURE (DEGR. C)


SES - COPPER CLIFF
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.5
HS
SL

SES - COPPER CLIFF
22/ 8/ 1978
1755
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
HS
TS


SES - COPPER CLIFF
24/ 8/ 1979
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.5
SL
POTENTIAL TEMP. (DEG. C)
WIND DIRECTION (DEGREES)


SES - COPPER CLIFF
24/ 8/ 1978
1315
HEIGHT (KM-MSL)
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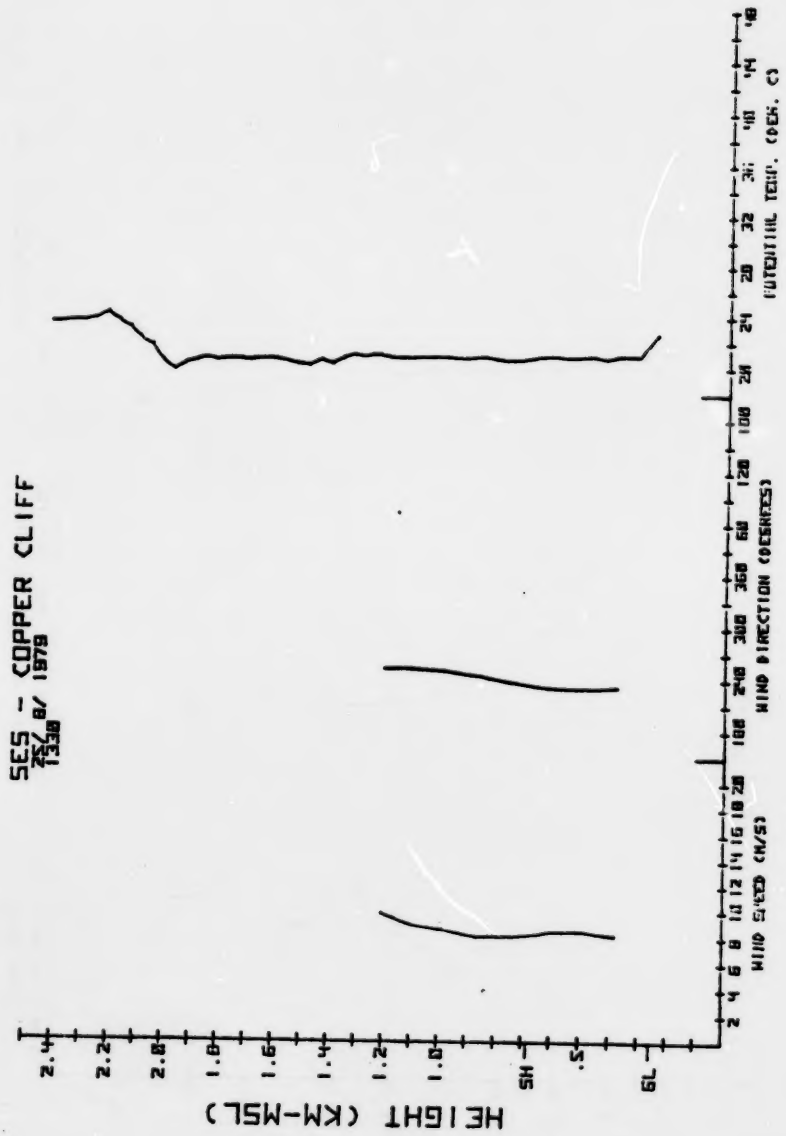
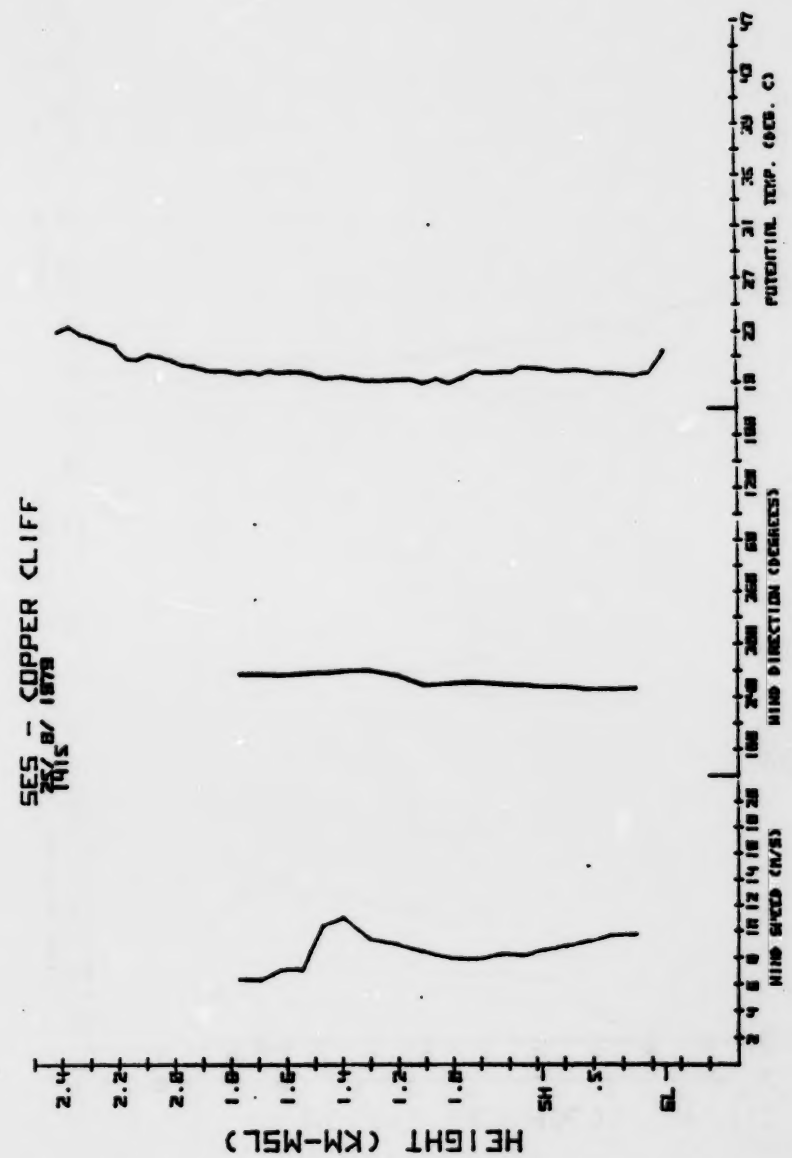
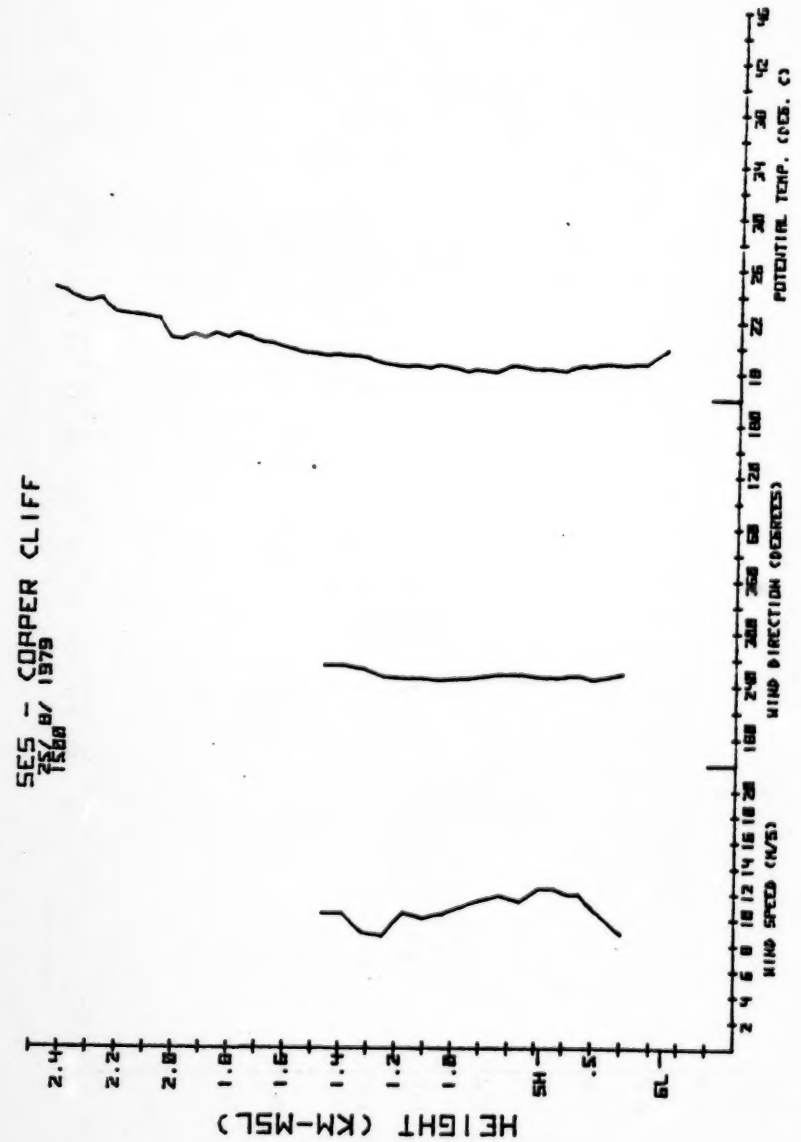
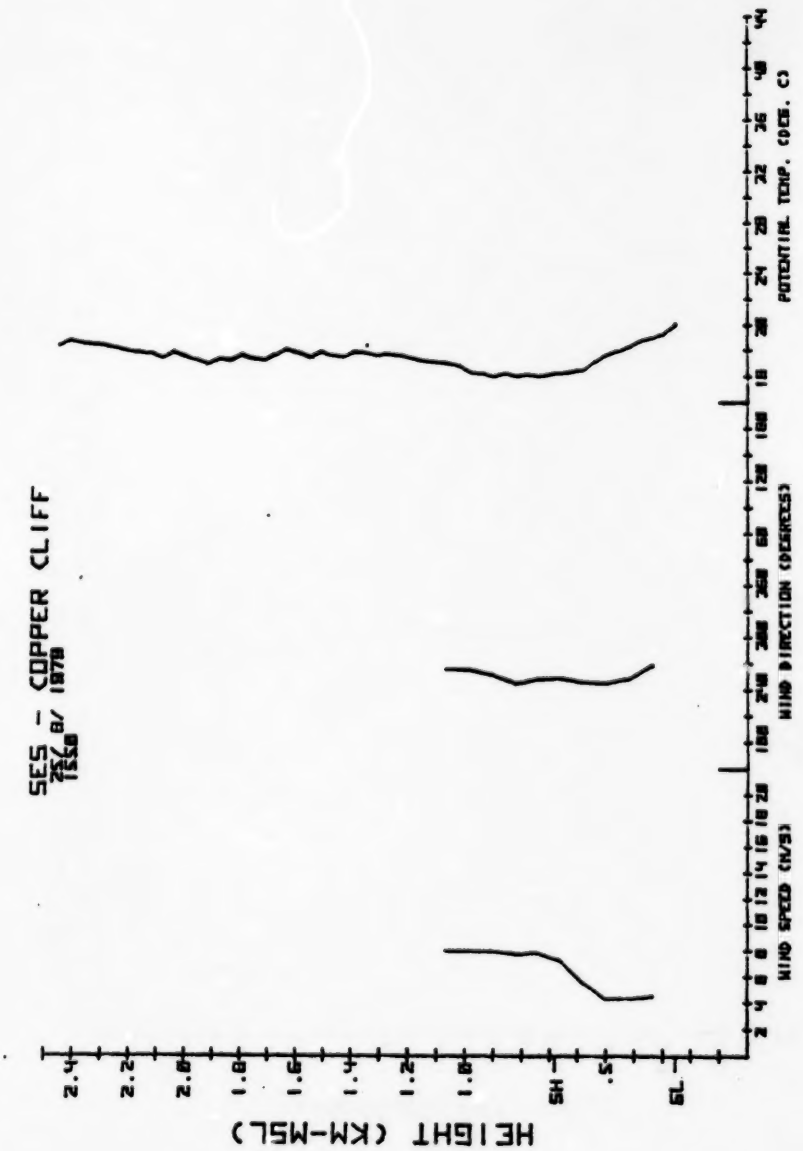
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
TP
SH
SL
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48
POTENTIAL TEMP. (DEG. C)
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340 360
WIND DIRECTION (DEGREES)
WIND SPEED (M/S)

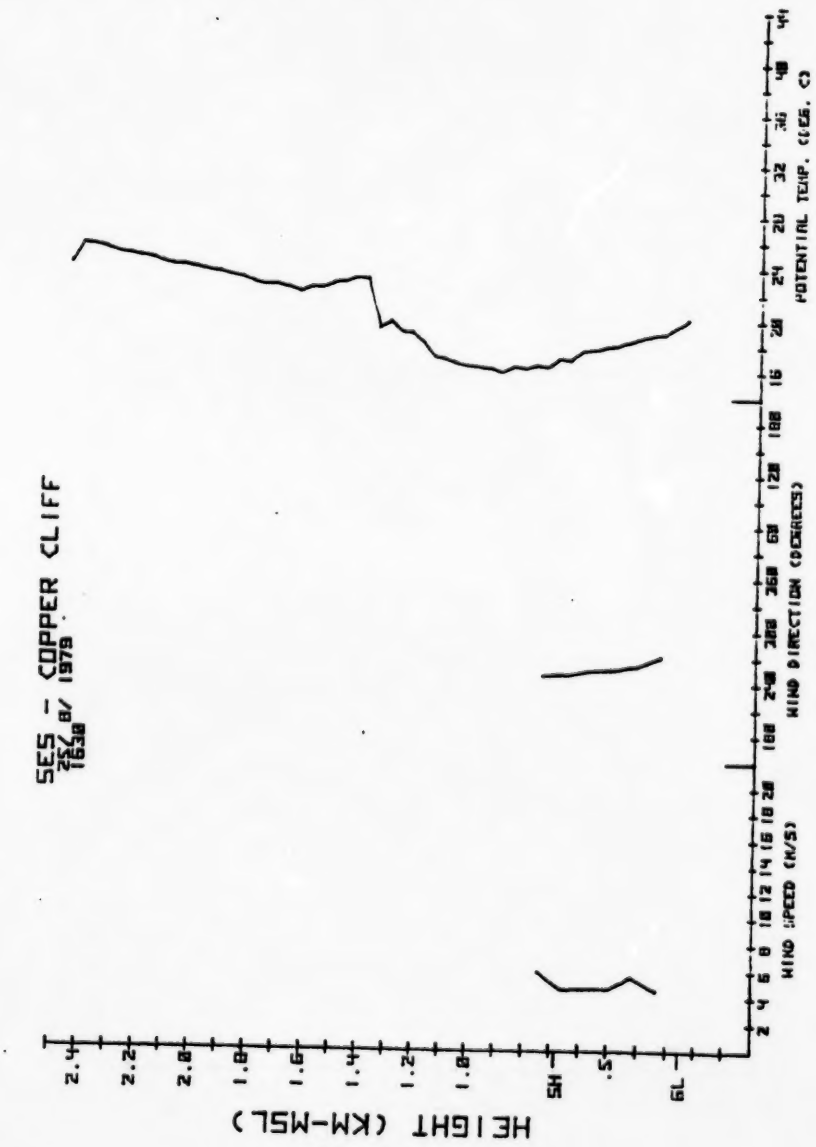
SES - COPPER CLIFF
12/15 8/ 1979
HEIGHT (KM-MSL)
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG. C)

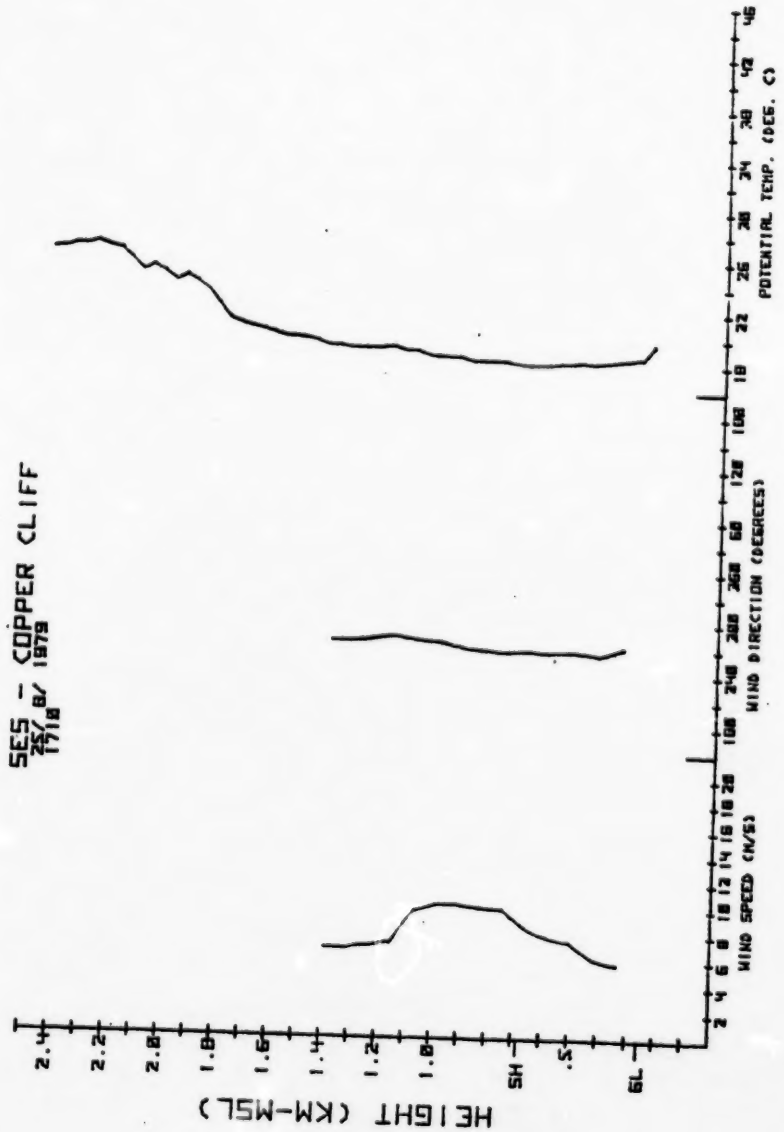

SES - COPPER CLIFF
1338 8/ 1979
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.5
HS
TS
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG. C)

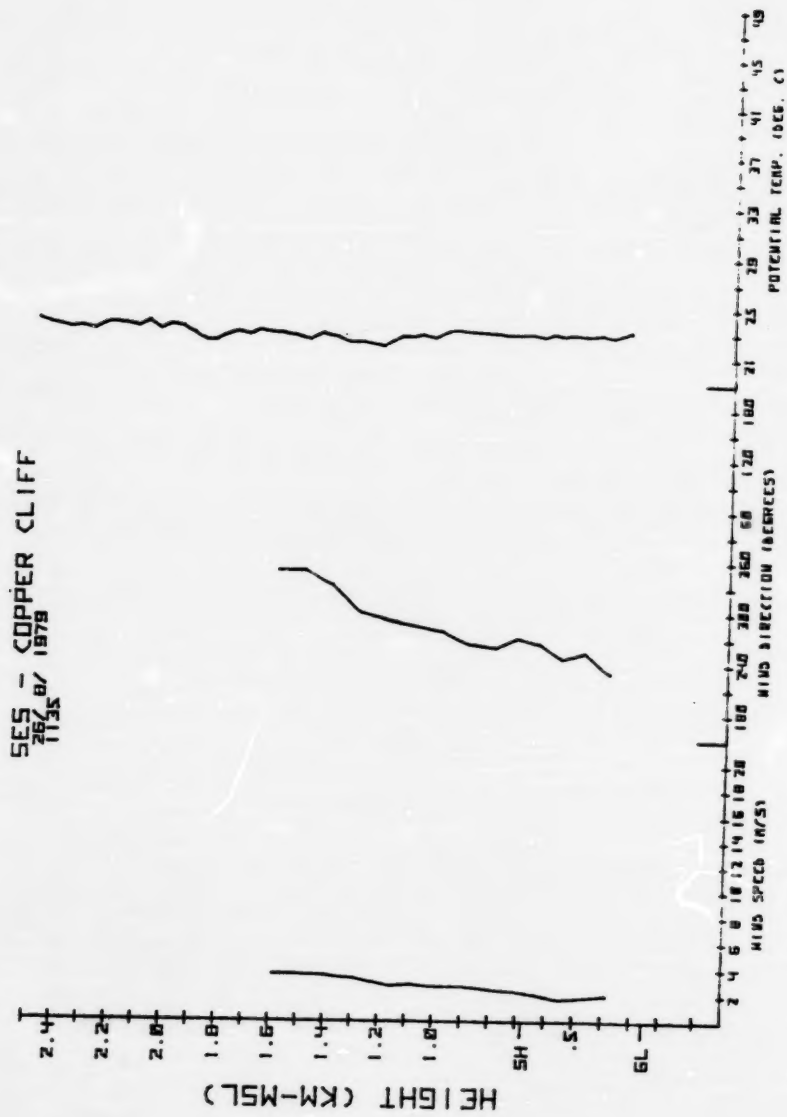

SES - COPPER CLIFF
HEIGHT (KM-MSL)
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG. C)

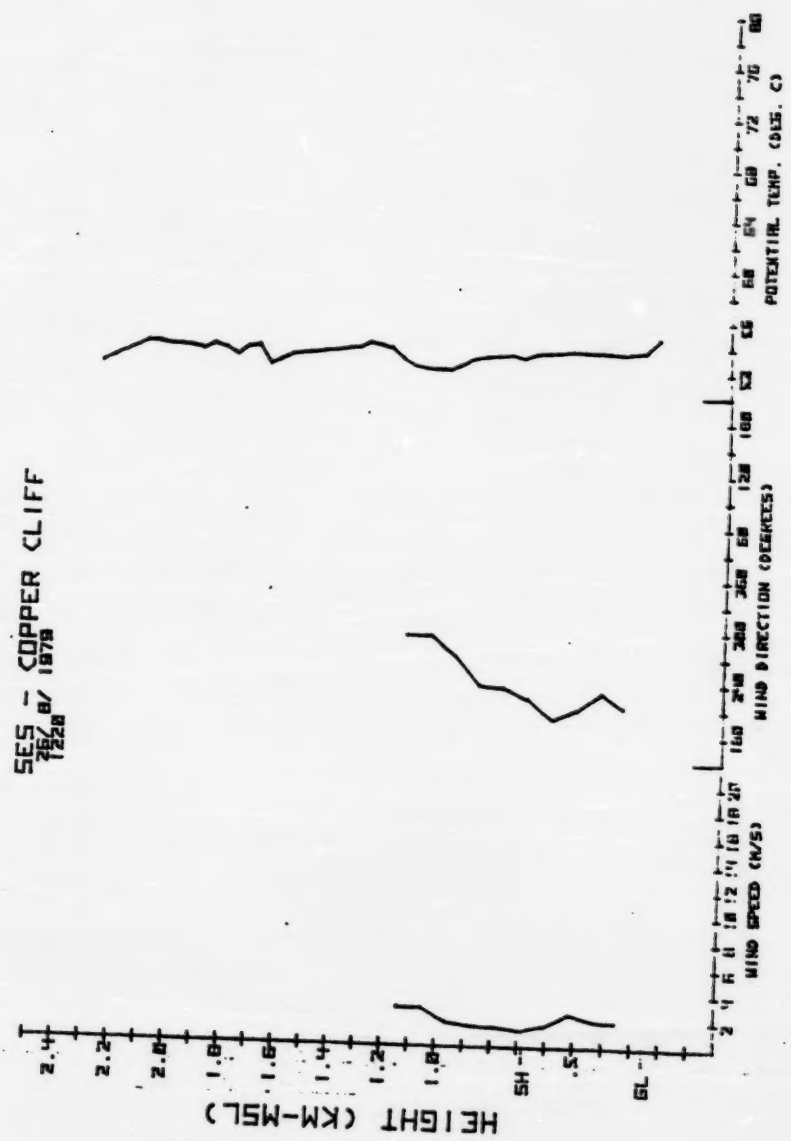

SES - COPPER CLIFF
25/ 8/ 1979
1500
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.5
SH
SL
WIND SPEED (KTS)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG. C)

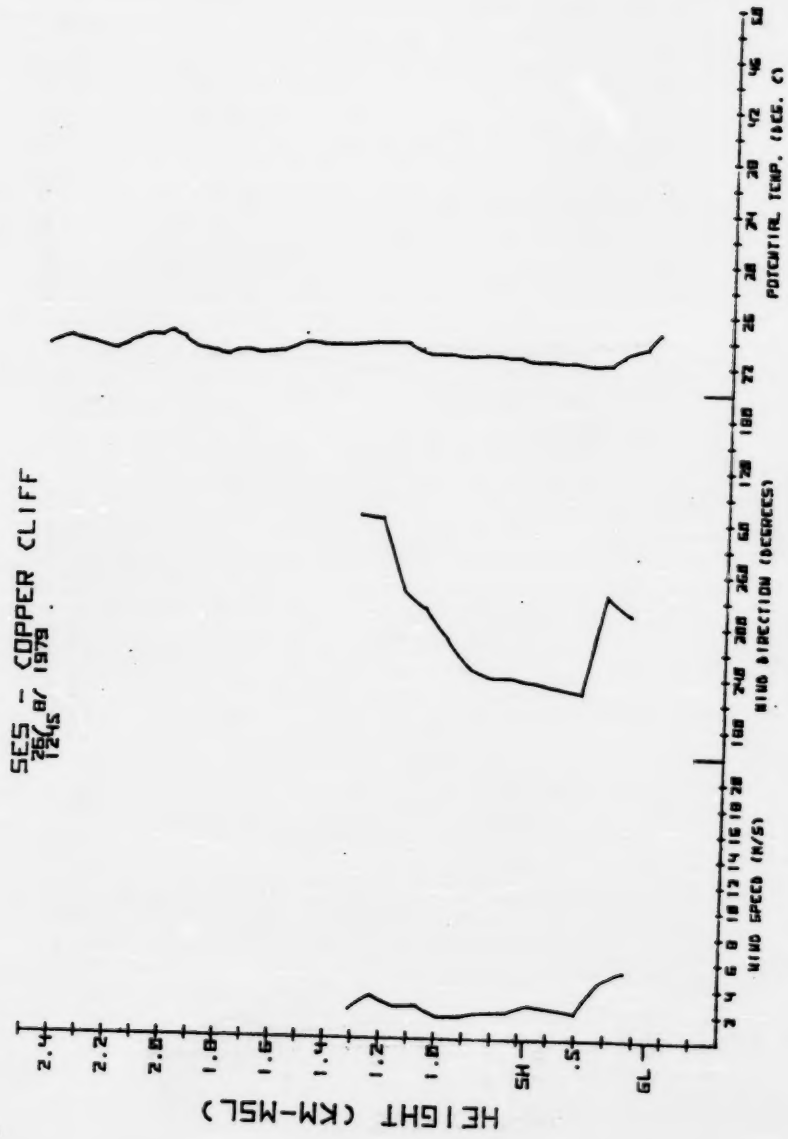

SES - COPPER CLIFF
25/ 8/ 1978
1558
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
TS
HS
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG. C)

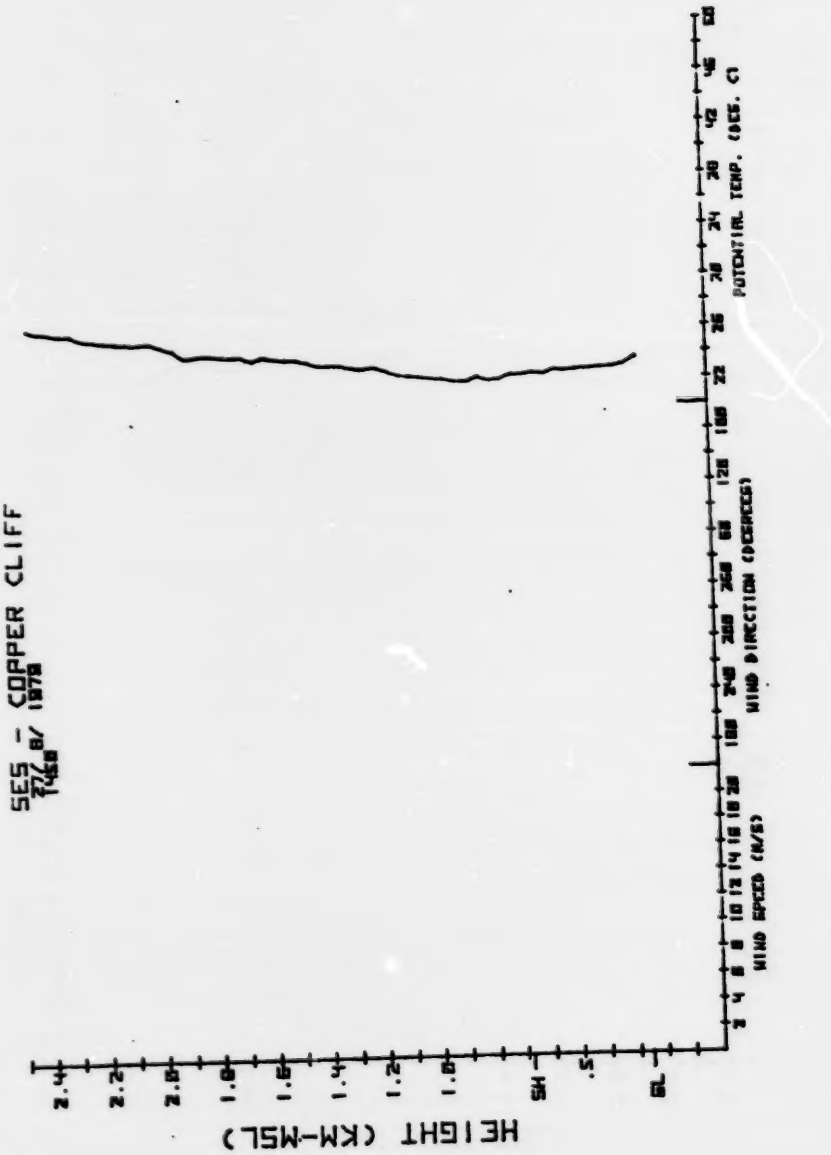

SES - COPPER CLIFF
25/8/ 1979
1630
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
HS
.5
TS
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG. C)

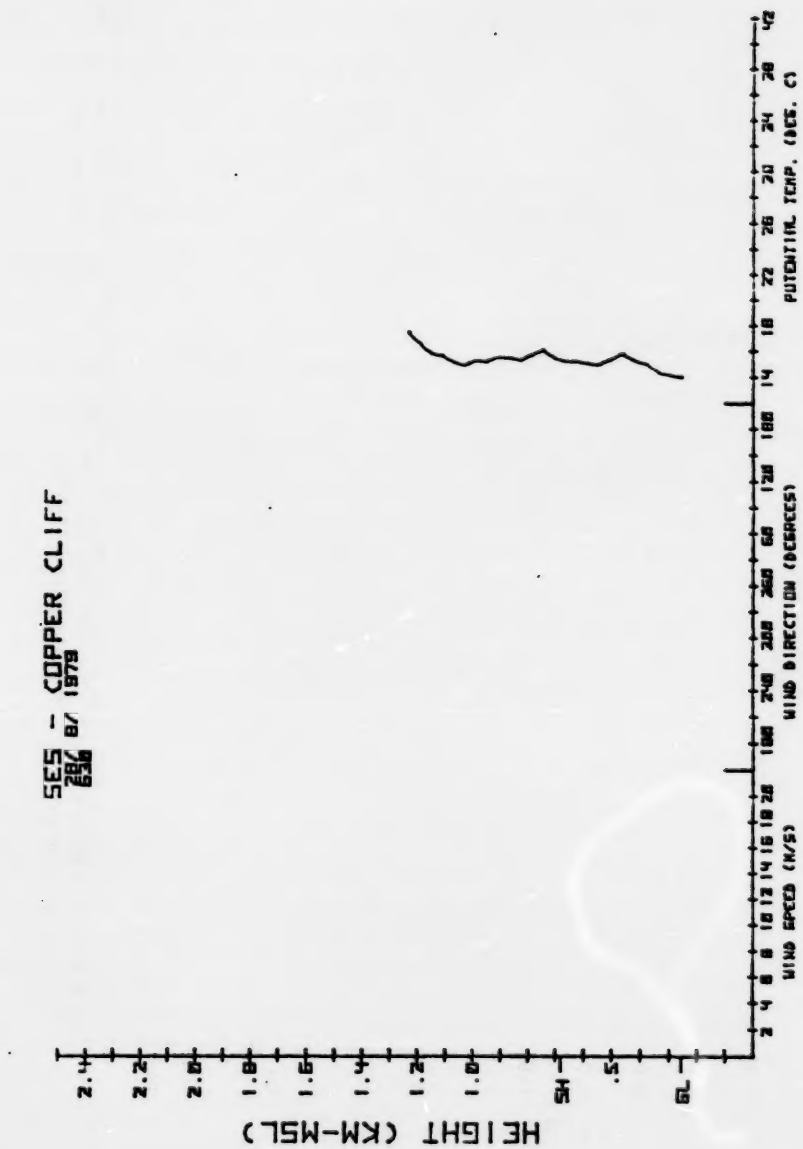

SES - COPPER CLIFF
25/ 8/ 1979
1718
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
HS
TG
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG. C)

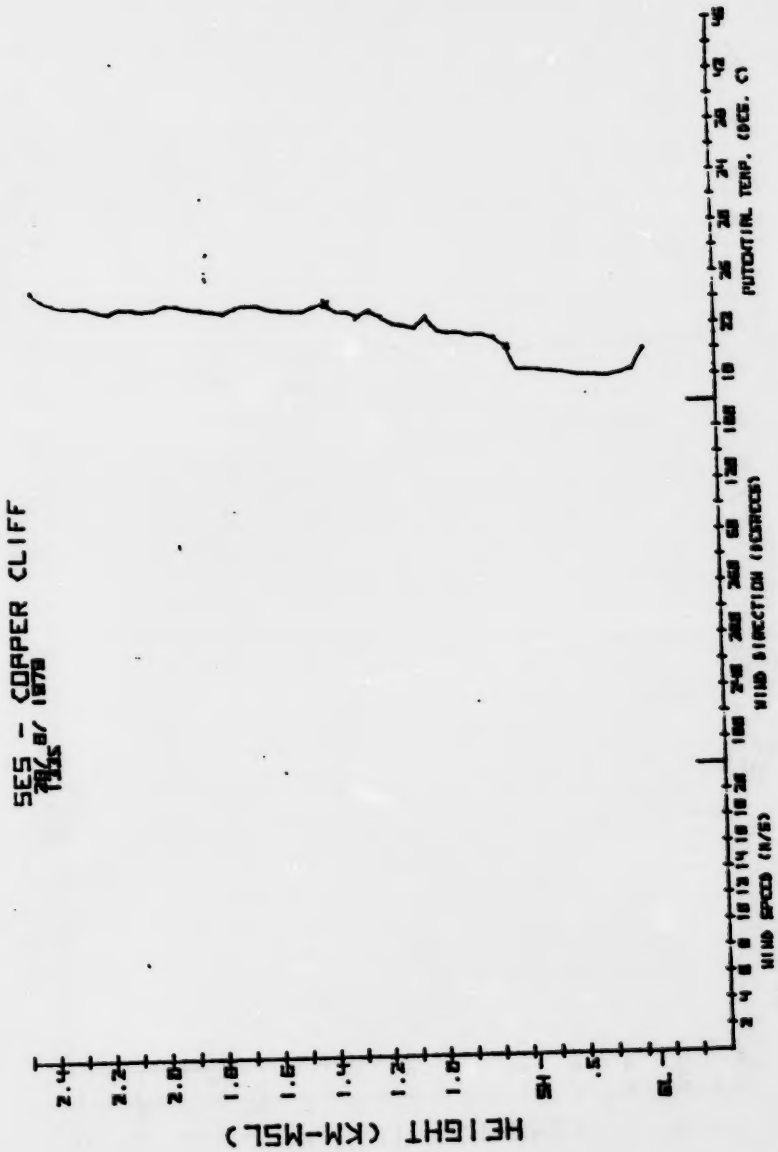

SES - COPPER CLIFF
26/ 8/ 1979
1135
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.5
HS
GL
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG. C)

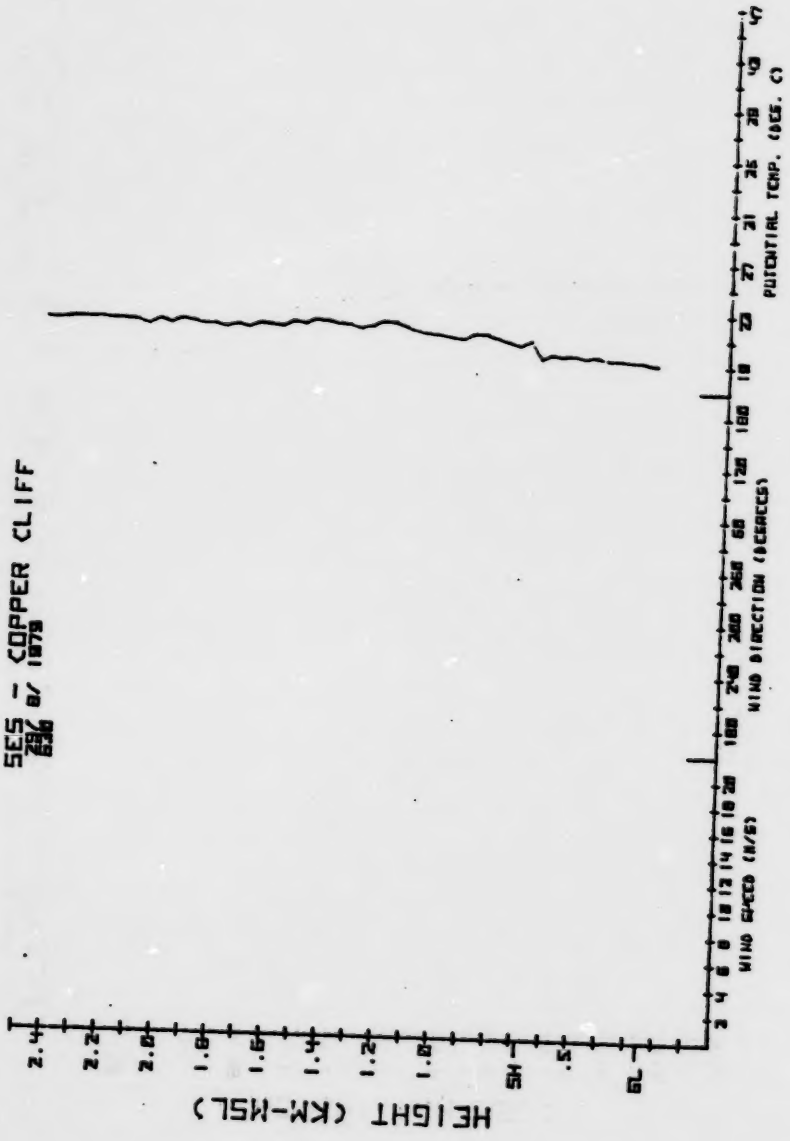

SES - COPPER CLIFF
28/ 8/ 1979
1228
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.5
HS
GL
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG. C)

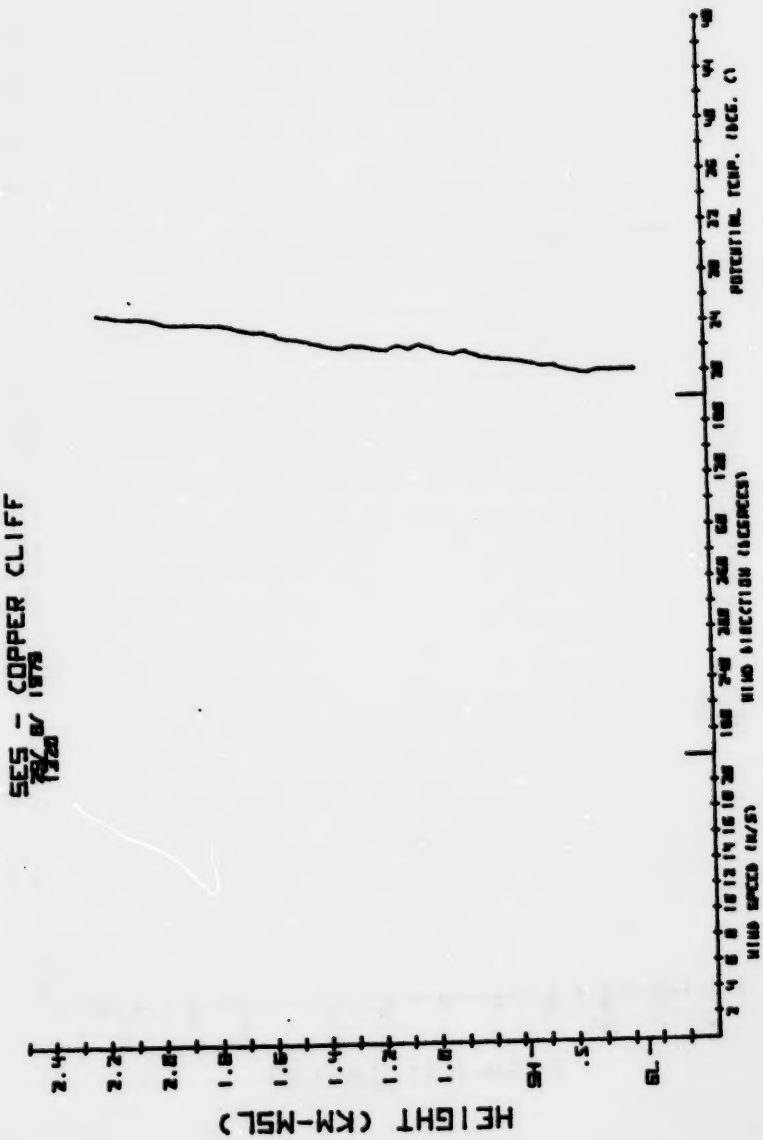

SES - COPPER CLIFF
26/ 8/ 1979
1245
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.5
SH
GL
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG. C)

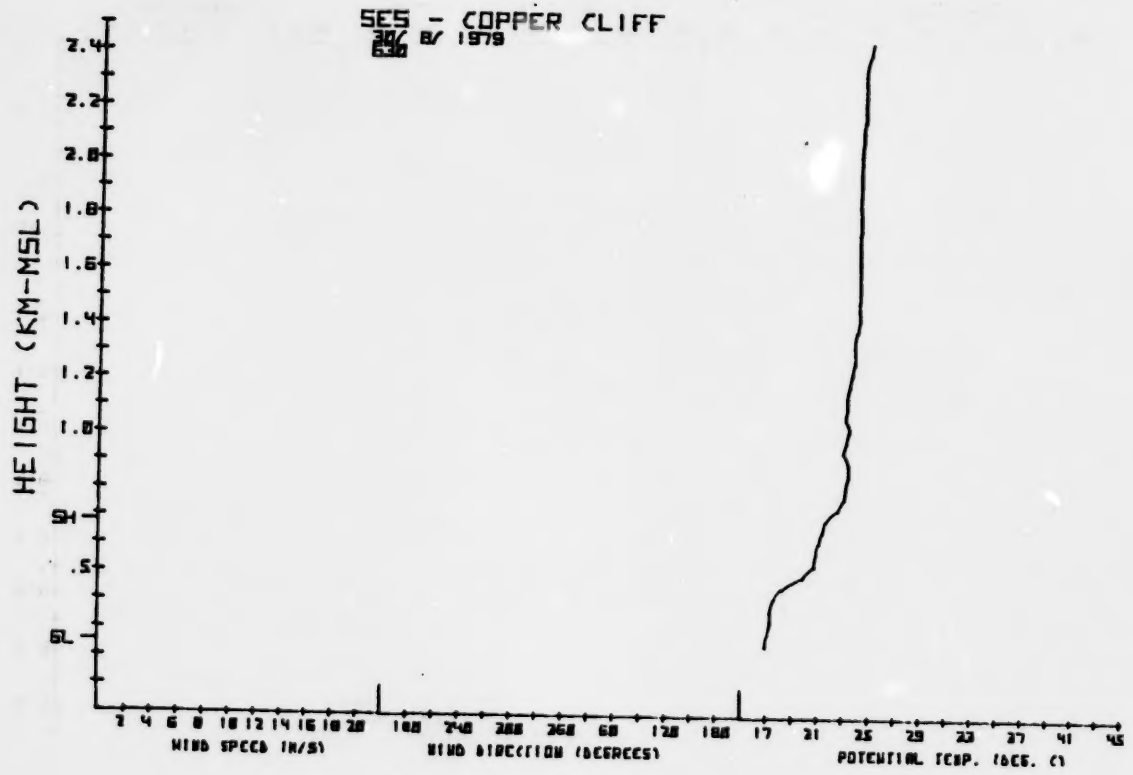

SES - COPPER CLIFF
HEIGHT (KM-MSL)
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG. C)

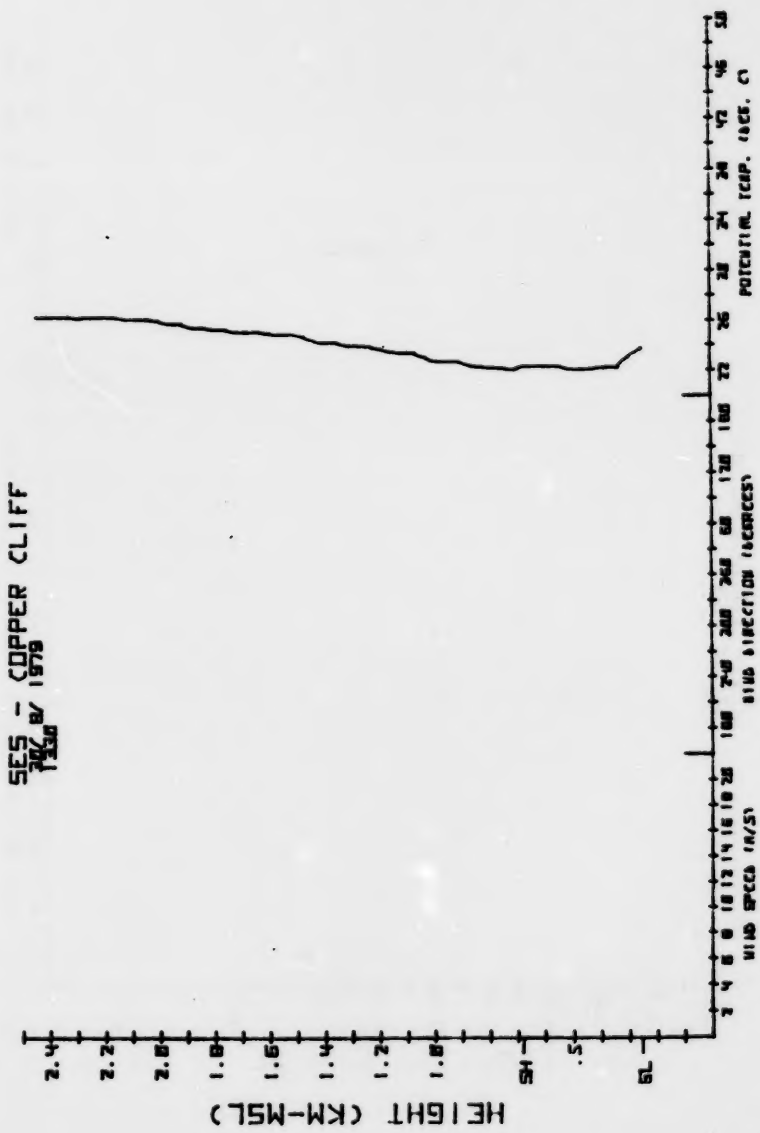

SES - COPPER CLIFF
28/ 8/ 1979
636
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
SH
.5
GL
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG. C)

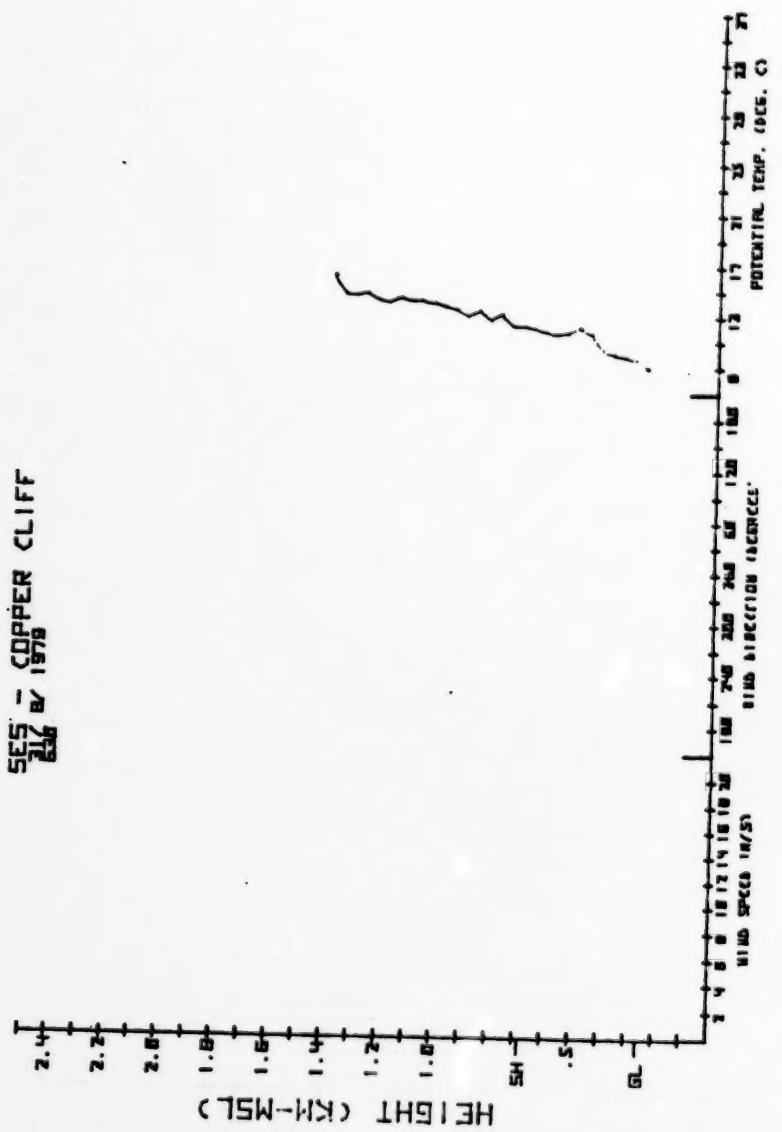

SES - COPPER CLIFF
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG. C)

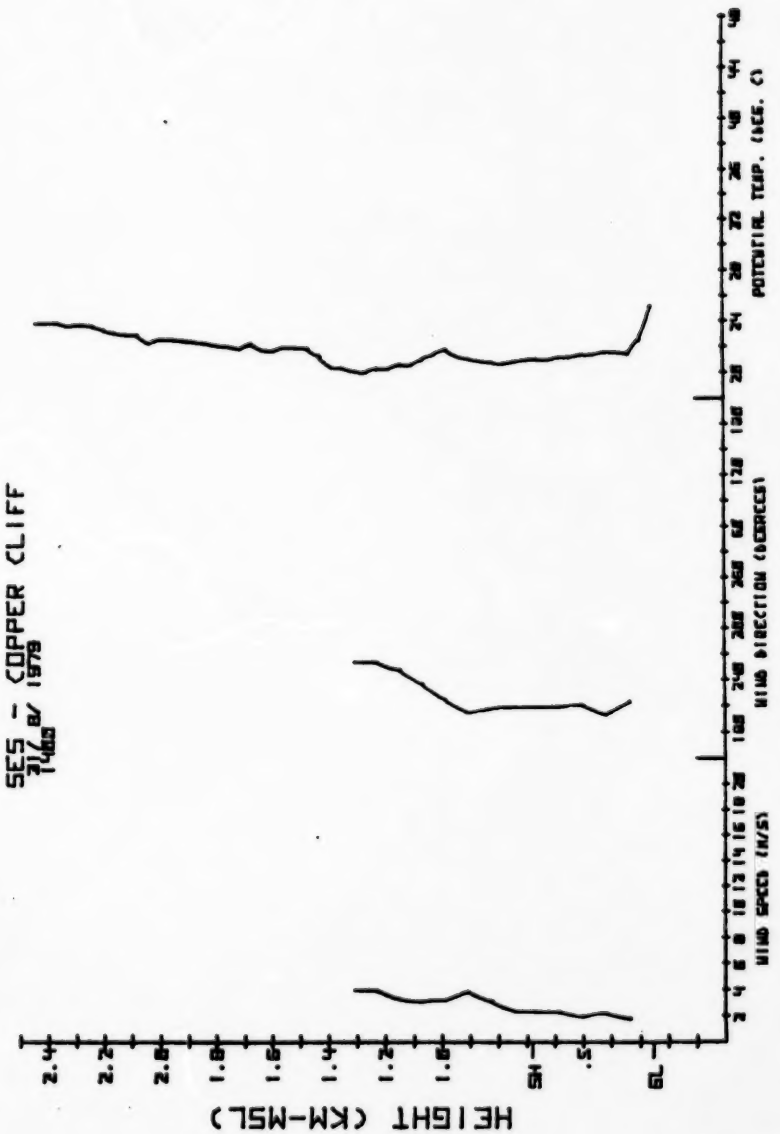

SES - COPPER CLIFF
29/6 8/ 1979
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.5
MS
GL
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG. C)


SES - COPPER CLIFF
HEIGHT (KM-MSL)
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG. C)


SES - COPPER CLIFF
30/
6:30
8/ 1979
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
SH
.5
SL
2 4 6 8 10 12 14 16 18 20
WIND SPEED (M/S)
180 240 280 260 60 120 180
WIND DIRECTION (DEGREES)
17 21 25 29 33 37 41 45
POTENTIAL TEMP. (DEG. C)


SES - COPPER CLIFF
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.5
SH
SL
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG. C)


SES - COPPER CLIFF
HEIGHT (KM-MSL)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.5
SH
GL
POTENTIAL TEMP. (DEG. C)


SES - COPPER CLIFF
HEIGHT (KM-MSL)
WIND SPEED (M/S)
WIND DIRECTION (DEGREES)
POTENTIAL TEMP. (DEG. C)